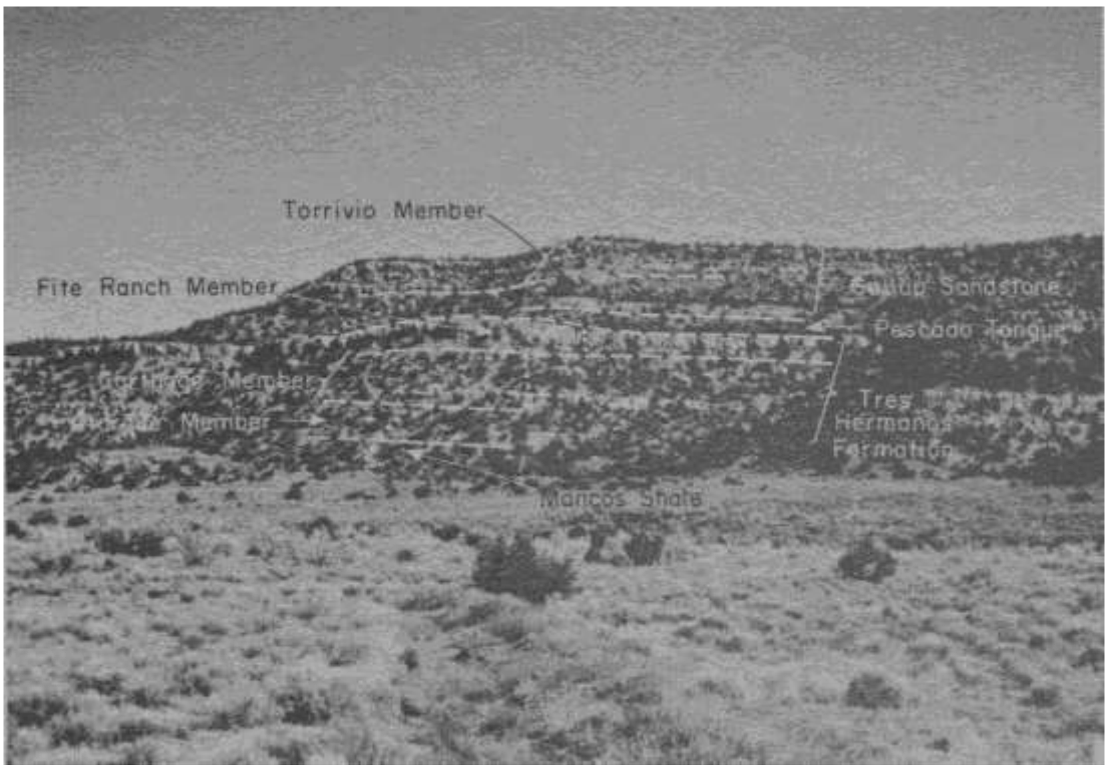
Circular 185 1983

Contributions to mid-Cretaceous paleontology and stratigraphy of NewMexico--part II



New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

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Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico—part II

compiled by Stephen C. Hook,
Getty Oil Company, Houston, TX

COVER—Pescado Creek section, control point 33, sec. 32, T. 11 N., R. 17 W., McKinley County, New Mexico

SOCORRO 1983

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Preface

This circular is the second in a series that contains short papers on the paleontology and stratigraphy of the mid-Cretaceous (Albian, Cenomanian, and Turonian) of New Mexico and surrounding areas. The first circular, Circular 180, contained three papers that dealt primarily with paleontologic aspects of the mid-Cretaceous of New Mexico. This circular contains three papers that are concerned primarily with stratigraphic aspects of the mid-Cretaceous of west-central New Mexico. A third circular is presently in the planning stages.

This series was initiated in 1981 under the guidance of Frank E. Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources, and is a reflection of the potential economic importance of the rocks of mid-Cretaceous age in New Mexico. These rocks contain not only nonmarine coal-bearing sequences but also marine organic-rich shale sequences that could serve as hydrocarbon source rocks.

The first three papers in this circular are the direct result of a combined effort by the New Mexico Bureau of Mines and Mineral Resources and the U.S. Geological Survey to evaluate the coal resource potential of and to map several 7 1/2-min quadrangles in west-central New Mexico. The nomenclature and correlation of middle Cenomanian through early Coniacian rocks in west-central New Mexico has long been a subject of controversy and confusion. Although some aspects of the nomenclature advocated in these first three papers, particularly the use of the Tres Hermanos Formation, remain controversial, the correlations have been substantiated by the detailed mapping efforts of personnel from the New Mexico Bureau of Mines and Mineral Resources and the U.S. Geological Survey in both the Acoma and Zuni Basins.

In addition, during the week of October 16-21, 1978, the New Mexico Bureau of Mines and Mineral Resources sponsored a field conference on Cretaceous stratigraphy in the Carthage coal field and in the Acoma, Zuni, and southern San Juan Basins. Participants included W. A. Cobban, A. R. Kirk, E. R. Landis, M. N. Machette, M. E. MacLachlan, C. H. Maxwell, S. L. Moore, and J. F. Robertson from the U.S. Geological Survey; C. M. Molenaar, then with Shell Oil Company; and G. L. Massingill, B. Robinson, D. E. Tabet, and me from the New Mexico Bureau of Mines and Mineral Resources. Although no consensus was reached on either correlation or nomenclature during that week, the trip allowed all the participants to view the field relationships of the rocks and laid the foundation for an informal meeting of the U.S. Geological Survey Geologic Names Committee on January 10, 1979. The nomenclature for the Cretaceous rocks in the Carthage coal field, Acoma, Zuni, and southern San Juan Basins was discussed at this meeting by many of the participants in the earlier field conference. The major point of contention at this meeting was use of the term Tres Hermanos Sandstone because of a vague definition and confusion surrounding its use since 1900. Of the two options available—revision or abandonment—the Geologic Names Committee felt that revision was the better course of action because the name would most likely be retained and used by other geologists even if formally abandoned by the U.S. Geological Survey.

At that time only Bill Cobban and I were working on the revision of the Tres Hermanos Sandstone. Later in 1979, C. M. Molenaar agreed to work with us on the paper despite his objections to the name "Tres Hermanos." The paper was considerably strengthened by the addition of Molenaar's measured sections and interpretations of depositional environments. It was a rare privilege for me to have worked with both Bill Cobban and "K" Molenaar on this paper.

Molenaar's paper in this circular on the Gallup Sandstone is an important contribution to mid-Cretaceous stratigraphy of New Mexico because it formally defines the extent of the Gallup Sandstone, establishes a principal reference section for the formation, and corrects some errors in previous regional correlations. The need for a paper• of this scope has been evident since February 2, 1978, when the Geologic Names Committee met in a formal session to consider the redefinition of the Gallup Sandstone. A group from the Uranium and Thorium Branch, which had been engaged for several years in detailed mapping in the San Juan Basin, proposed removal of the Torrivio Member from the Gallup Sandstone and classifying it as the Torrivio Bed of the Dilco Member of the Crevasse Canyon Formation. The Geologic Names Committee recommended (partial list) that 1) the Torrivio Member be retained as the top of the Gallup Sandstone and 2) for the time being, until better information is available, the lowest level of the base of the Gallup remain as presently recognized by the U.S. Geological Survey. Molenaar's paper formalizes both of these recommendations by establishing a principal reference section for the Gallup and by showing in regional cross sections that the Gallup Sandstone is separated from the underlying Tres Hermanos Formation (previously called the Atarque Member of the Gallup Sandstone) by a significant transgressive shale unit.

The third paper in this set of interrelated stratigraphic papers is by McLellan and others and establishes the stratigraphic nomenclature for the upper part of the Cretaceous sequence in the southern Zuni Basin. Together the three papers provide the detailed stratigraphic framework that has been developed in the course of mapping in the Zuni and Acoma Basins.

The fourth paper by W. A. Cobban and me is the first in this series to discuss mid-Cretaceous stratigraphy and paleontology outside the borders of New Mexico. Bill and I first went to Gold Hill in Jeff Davis County, Texas, because of published reports indicating that two ammonites that were stratigraphically and temporally well separated in New Mexico occurred in the same bed at Gold Hill. Either the biostratigraphic relationships we had established in New Mexico were in error, or an unconformity was present in the sequence in Texas. Our examination of the outcrop revealed that a significant middle Turonian unconformity had juxtaposed the two faunas in a single bed composed of worn, phosphatized, encrusted internal molds of ammonites. This work was done in cooperation with the Bureau of Economic Geology, Austin, Texas.

The field work that resulted in these papers was completed while I was employed at the New Mexico Bureau of Mines and Mineral Resources from 1976 to 1981. I thank Frank E. Kottlowski for his guidance and continued support. The excellent typing, drafting, and editing also were supplied by the New Mexico Bureau of Mines and Mineral Resources.

Houston, Texas
February 28, 1983

Stephen C. Hook
Getty Oil Company,
Exploration and Production
Research Center

A contribution to Project Mid-Cretaceous Events

Contents

TABLES

FIGURES

SHEET

STRATIGRAPHY AND REVISION OF NOMENCLATURE OF UPPER CENOMANIAN TO TURONIAN (UPPER CRETACEOUS) ROCKS OF WEST-CENTRAL NEW MEXICO

by S. C. Hook, *Getty Oil Company, Exploration and Production Research Center, Houston, Texas,* and
C. M. Molenaar and W. A. Cobban, *U.S. Geological Survey, Denver, Colorado*

Abstract

The mid-Cretaceous Tres Hermanos Sandstone of Herrick (1900), later changed to the Tres Hermanos Sandstone Member of the Mancos Shale by Lee (1912), is raised in stratigraphic rank to the Tres Hermanos Formation. The Tres Hermanos Formation is a northeastward-directed elastic wedge of nearshore marine and nonmarine rocks that was deposited in west-central New Mexico during early and late Turonian time. This wedge, which ranges in thickness from 200 to 300 ft (61-91 m), except near its seaward extent where it grades into the Mancos Shale, conformably overlies the Rio Salado Tongue (new name) of the Mancos Shale and is conformably to disconformably overlain by the D-Cross or Pescado Tongue of the Mancos Shale. The Tres Hermanos Formation is subdivided into three members: the lower, regressive marine Atarque Sandstone Member (revised to member rank in west-central New Mexico); the medial, generally nonmarine Carthage Member (new name); and the upper, transgressive marine Fite Ranch Sandstone Member (new name). The outcrop belt of the Tres Hermanos Formation along the Rio Salado in Tps. 2 and 3 N., Rs. 5 and 6 W., Socorro County, is designated as the type area for the formation. A principal reference section for the Tres Hermanos is established in this report at Carthage in southeast Socorro County; other reference sections for it are established in the type area in northwest Socorro County and along Pescado Creek in southern McKinley County. The D-Cross and Pescado Tongues of the Mancos Shale represent a significant transgressive episode that separates the Tres Hermanos from the younger Gallup Sandstone. Consequently, the Tres Hermanos Formation, previously referred to as the Atarque Member of the Gallup Sandstone or as the lower Gallup, is removed from the Gallup. The Rio Salado Tongue of the Mancos Shale is defined as that part of the Mancos Shale separating the underlying Twowells Tongue of the Dakota Sandstone from the overlying Tres Hermanos Formation (or Atarque Sandstone to the southwest where the Tres Hermanos terminology is not used). In west-central New Mexico, the Rio Salado Tongue ranges in thickness from about 200 to 300 ft (6191 m) and consists of a lower calcareous shale and limestone unit and an upper noncalcareous clay-shale unit that intertongues with or grades into the overlying Tres Hermanos Formation. Within the lower unit, the Bridge Creek Limestone has been identified and given the stratigraphic rank of beds. The contacts of the Rio Salado Tongue with both the overlying and underlying rock units are conformable.

Introduction

Recent biostratigraphic and stratigraphic work on mid-Cretaceous rocks of west-central New Mexico by Hook and Cobban (1979, 1980, 1981a) and Cobban and Hook (1979a, 1979b) has indicated a need for revision of mid-Cretaceous stratigraphic nomenclature and correlation. This paper is part of a much larger project on the stratigraphy, biostratigraphy, environments of deposition, and correlation of mid-Cretaceous rocks in west New Mexico. In this paper we are revising the Tres Hermanos Sandstone of Herrick (1900), based on our interpretation of Herrick's description, and expanding it into a more encompassing unit called the Tres Hermanos Formation. Further, we subdivide the formation into three members and, by means of two cross sections, show the relationships between the Tres Hermanos Formation and overlying and underlying formations in west-central New Mexico. Reference sections for the Tres Hermanos Formation are established in the type area in the Rio Salado valley 40 mi (65 km) northwest of Socorro, at Carthage, and in the Zuni Basin along Pescado Creek (fig. 1). In addition, the shale tongue lying between the Tres Hermanos Formation and the Twowells Tongue of the Dakota Sandstone is herein named the Rio Salado Tongue of the Mancos Shale; its type section is in the Rio Salado valley, within the type area of the Tres Hermanos Formation.

Because the emphasis of this report is on the Tres Hermanos Formation, and the definition of the Rio Salado Tongue is based on recognition of the overlying Tres Hermanos, the Tres Hermanos Formation will be discussed first.

Since the name Tres Hermanos Sandstone was introduced in the geologic literature of New Mexico (Herrick, 1900;

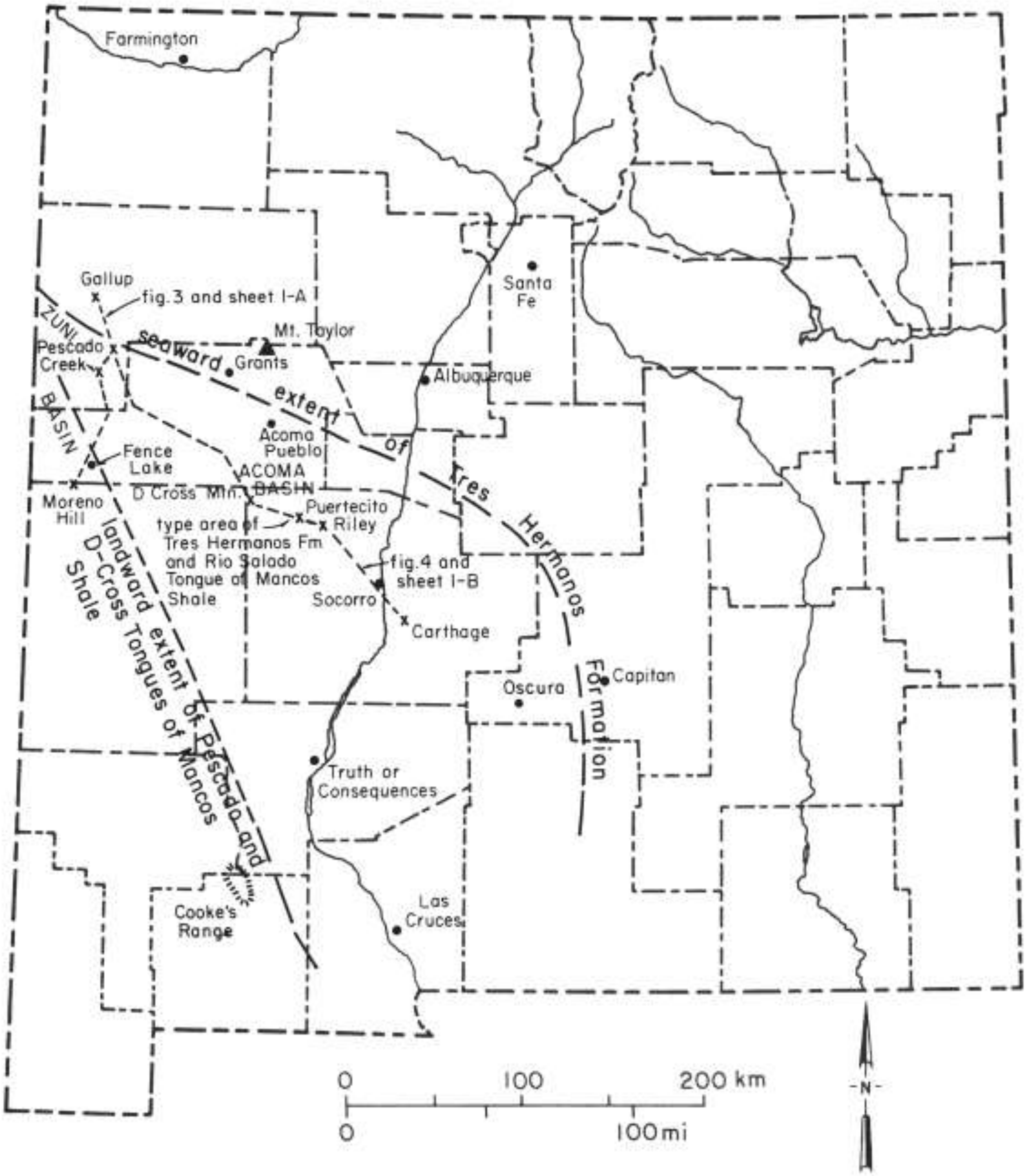

FIGURE 1—MAP OF NEW MEXICO SHOWING LINES OF SECTIONS for figs. 3 and 4 and sheet 1-A and 1-B (in back pocket), seaward extent of Tres Hermanos Formation, and landward extent of Pescado and D-Cross Tongues of Mancos Shale

Herrick and Johnson, 1900), the term has been applied to virtually every sandstone unit low in the Mancos Shale (table 1). For example, in the Mount Taylor area 50 mi (80 km) west of Albuquerque (fig. 1), the name Tres Hermanos Sandstone has been applied to all three prominent sandstone units (now correctly identified as the Twowells, Paguate, and Cubero Tongues of the Dakota Sandstone) in the lower 350 ft (107 m) of the Mancos Shale (Hunt, 1936, p. 40).

Herrick (1900, p. 341) originally applied the name Tres Hermanos Sandstone to " . . a band of sandstone with enormous concretions . . ." just east of Tres Hermanos Peaks, three basaltic necks in the Rio Salado valley, 40 mi (65 km) northwest of Socorro. According to Herrick's (1900, p. 341) written description of Cretaceous geology in the Rio Salado valley, the band of sandstone with enormous concretions was the second sandstone above the base of the Mancos Shale. Herrick, who did not recognize the intertonguing and age relationships of the Dakota Sandstone and Mancos Shale (Landis and others, 1973), erroneously believed that the sequence of Cretaceous sandstones and shales exposed in the Rio Salado valley was identical to the sequence he had studied in the Rio Puerco valley west of Albuquerque. Consequently, he misapplied the name Tres Hermanos Sandstone to the second sandstone above the Dakota Sandstone in the Rio Puerco valley. Later, Lee (1912), referring to the sandstone in the Rio Puerco area and areas to the northeast, designated the unit as the Tres Hermanos Sandstone Member of the Mancos Shale. Subsequent work by Dane and others (1971) and Landis and others (1973) has shown that this sandstone in the Rio Puerco valley is the Paguate Tongue

TABLE 1—APPLICATION OF NAME "TRES HERMANOS SANDSTONE" SINCE 1900.

Author(s)	Area (County)	Name applied	Present stratigraphic assignment
Herrick (1900)	Rio Salado (Socorro)	Tres Hermanos Sandstone	Tres Hermanos Formation
Herrick (1900)	Rio Puerco (Sandoval)	Tres Hermanos Sandstone	Paguate Tongue of Dakota Sandstone
Herrick and Johnson (1900)	Rio Puerco (Sandoval)	Tres Hermanos Sandstone	Paguate Tongue of Dakota Sandstone
Lee (1912, 1916, 1917)	Cerrillos (Santa Fe)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Lee (1912, 1916, 1917)	Tijeras (Santa Fe)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Stanton (1913)	Rio Puerco (Sandoval)	Tres Hermanos Sandstone	Paguate Tongue of Dakota Sandstone
Lee (1916)	Carthage (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Dakota Sandstone (main body)
Lee (1917)	Casa Salazar (Sandoval)	Tres Hermanos Sandstone (upper and lower plates)	Paguate and Cubero Tongues of Dakota Sandstone
Lee (1917)	Rio Puerco coal field (Sandoval)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Lee (1917)	Hagan coal field (Sandoval)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Winchester (1920)	Puertecito (Socorro)	Tres Hermanos? Sandstone (Member of Miguel Formation)	Twowells Tongue of Dakota Sandstone or Atarque Sandstone Member of Tres Hermanos Formation
Darton (1928)	north-central New Mexico (Sandoval)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
	Tijeras (Santa Fe)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Hunt (1936)	Mount Taylor coal field (Cibola)	Tres Hermanos Sandstone Sandstone no. 3 Sandstone no. 2 Sandstone no. 1	Twowells Tongue of Dakota Sandstone (3) Paguate Tongue of Dakota Sandstone (2) Cubero Tongue of Dakota Sandstone (1)
Rankin (1944)	Cerrillos (Santa Fe)	Tres Hermanos	Paguate Tongue of Dakota Sandstone
Rankin (1944)	Rio Puerco (Sandoval)	Tres Hermanos	Twowells Tongue? of Dakota Sandstone
Rankin (1944)	Lamy (Santa Fe)	Tres Hermanos	Paguate Tongue of Dakota Sandstone
Pike (1947)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone	Twowells Tongue of Dakota Sandstone
Pike (1947)	Atarque (Cibola)	Tres Hermanos Sandstone	Paguate Tongue of Dakota Sandstone
Cobban and Reeside (1952)	Datil Mountains coal field (Catron and Cibola)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Cobban and Reeside (1952)	Mount Taylor region (Cibola)	Tres Hermanos Sandstone Member of Mancos Shale	Cubero, Paguate, or Twowells Tongue of Dakota Sandstone

TABLE 1 (con't)

Author(s)	Area (County)	Name applied	Present stratigraphic assignment
Cobban and Reeside (1952)	Cerrillos (Santa Fe)	Tres Hermanos Sandstone (Member of Mancos Shale)	Paguate Tongue of Dakota Sandstone
Stearns (1953)	Galisteo–Tonque (Santa Fe)	Tres Hermanos Sandstone Member of Graneros Shale	Paguate Tongue of Dakota Sandstone
Dane and others (1957)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Dane and others (1957)	Puertecito (Socorro)	Tres Hermanos Sandstone (Member of Mancos Shale)	Dakota Sandstone (main body)
Disbrow and Stoll (1957)	Cerrillos (Santa Fe)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Givens (1957)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Tonking (1957)	Puertecito (Socorro)	Tres Hermanos Sandstone Member of La Cruz Peak Formation	Twowells Tongue of Dakota Sandstone
Jicha (1958)	Mesa del Oro (Socorro and Cibola)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Dane (1959)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Dane (1959)	Puertecito (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Dakota Sandstone (main body)
Gadway (1959)	west-central New Mexico (McKinley, Cibola, and Catron)	Tres Hermanos Sandstone	Twowells Tongue of Dakota Sandstone
Dane (1960)	northwestern New Mexico (San Juan and McKinley)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Kottlowski (1963)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Owen (1963)	southern San Juan Basin (McKinley)	Tres Hermanos Sandstone Member of Dakota Sandstone	Paguate and Twowells Tongues of Dakota Sandstone
Foster (1964)	Salt Lake coal field (Catron)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Foster (1964)	Datil Mountains coal field (Catron and Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Paguate Tongue of Dakota Sandstone
Foster (1964)	D Cross Mountain (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Owen (1964)	San Juan Basin (San Juan and McKinley)	Tres Hermanos Member of Dakota Formation	Paguate and Twowells Tongues of Dakota Sandstone
Owen (1966)	San Juan Basin (Socorro, Cibola and Sandoval)	Tres Hermanos Sandstone Member of Dakota Sandstone	Twowells Tongue of Dakota Sandstone

TABLE 1 (con't)

Author(s)	Area (County)	Name applied	Present stratigraphic assignment
Marvin (1967)	Grants–Defiance monocline (Cibola, McKinley, and Apache)	Dakota Sandstone–Tres Hermanos Sandstone	Cubero, Paguate, and Twowells Tongues of Dakota Sandstone
Dane and others (1971)	Rio Salado (Socorro)	Tres Hermanos Sandstone	Tres Hermanos Formation (part)
Beaumont and others (1976)	western San Juan Basin (McKinley and San Juan)	Tres Hermanos Sandstone Member of Mancos Shale	Twowells Tongue of Dakota Sandstone
Cobban and Hook (1979a)	Carthage (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Cobban and Hook (1979b)	west-central New Mexico (Lincoln, Sierra, Socorro, and Cibola)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Hook and Cobban (1979)	Puertecito (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Tabet (1979)	Jornada del Muerto coal field (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Baker and Wolberg (1981)	Sevilleta Grant (Socorro)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Brod and Stone (1981)	Ambrosia Lake–San Mateo (McKinley and Cibola)	Tres Hermanos Sandstone	Twowells Tongue of Dakota Sandstone
La Fon (1981)	southern San Juan Basin (Sandoval)	Tres Hermanos Sandstone	Tres Hermanos Formation
Place and others (1981)	Smith Lake district (McKinley)	Tres Hermanos [Sandstone Member] of Mancos Formation	Twowells Tongue and main body of Dakota Sandstone
Seager (1981)	southern San Andres Mountains (Doña Ana)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Maxwell (1982)	Laguna–Grants area (Cibola)	Tres Hermanos Sandstone Member of Mancos Shale	Tres Hermanos Formation
Molenaar (1983)	western New Mexico (McKinley, Cibola, Catron, Sierra, and Socorro)	Tres Hermanos Formation	Tres Hermanos Formation
Osburn (1983)	Alamo Reservation (Socorro)	Tres Hermanos Formation	Tres Hermanos Formation

of the Dakota Sandstone and is stratigraphically lower than Herrick's Tres Hermanos Sandstone in its type area, the Rio Salado valley.

Confusion surrounding the identity of Herrick's Tres Hermanos Sandstone in the Rio Salado valley has been almost as great as in the Rio Puerco valley. Winchester (1920) was unsure whether the term Tres Hermanos should be applied to the first or second sandstone above the Dakota in the Rio Salado area near Puertecito. Pike (1947, p. 66) applied the name Tres Hermanos Sandstone to the first sandstone above the Dakota (now correctly assigned to the Twowells Tongue of the Dakota) in the D Cross Mountain area, 12 mi (19 km) west of the area of Herrick's Tres Hermanos, but noted that the Tres Hermanos could occur as one or more massive sandstones near the base of the Mancos Shale. Pike (1947, p. 32), however, correctly identified the type locality of the Tres Hermanos as " . . probably a mile east of Tres Hermanos Buttes, three volcanic necks in Alamosa Creek [Rio Salado] valley . . . ," but he failed to use this information in correctly identifying the Tres Hermanos elsewhere.

Pike's miscorrelation of the Twowells, which he had named in the Zuni Basin to the northwest, with the Tres Hermanos was accepted by later workers in the area frbm D Cross Mountain to Puertecito in west-central New Mexico (Tonking, 1957; Givens, 1957; Dane and others, 1957; Dane, 1959). The pioneering work of Dane and others (1971, p. B19) on intertonguing of the Dakota Sandstone and Mancos Shale led to the realization that ". . . the sandstone to which Herrick (1900, p. 341) originally applied the name Tres Hermanos is a sandstone 150 to 200 ft stratigraphically above the sandstone identified as Tres Hermanos (correctly Twowells) of the Rio Salado valley. This higher sandstone crops out about 1 mile east of Tres Hermanos Buttes (Peaks), . . . where it is a 'band of sandstone with enormous concretions' as required by Herrick's (1900) description." Dane and others (1971, p. B20) restricted the name Tres Hermanos to this higher sandstone, but failed to describe the stratigraphic and geographic limits of the unit.

Even though the correct identity of the Tres Hermanos Sandstone Member has been in the literature for 12 yrs, the Twowells Tongue is still often incorrectly identified as the Tres Hermanos Sandstone Member (see table 1). This miscorrelation is due in part to an inadequate definition and to a lack of type and reference sections.

In the Zuni Basin south of Gallup, correlative strata of what we are calling the Tres Hermanos Formation have been either miscorrelated or included in an expanded definition of the Gallup Sandstone and called lower part of Gallup Member of the Mesaverde Formation (or Group) or Atarque Member of the Mesaverde Formation (Pike, 1947; Dane, 1959; Dane and others, 1957; Molenaar, 1973, 1974).

Although we, the authors, are all in substantial agreement on the correlations and stratigraphic relationships portrayed on sheet 1 (in back pocket), we are in disagreement on the nomenclature used. Two of us (Hook and Cobban) believe that the name "Tres Hermanos" is an intrinsic part of Cretaceous nomenclature of New Mexico and should be preserved by a revision that sets specific stratigraphic and geographic boundaries on the formation and is in compliance with the American Code of Stratigraphic Nomenclature. Molenaar, on the other hand, thinks that it would be best to apply a new name and abandon the term Tres Hermanos because of the 83 yrs of confusion surrounding its use and the vagueness of the original definition.

An informal meeting of the U.S. Geological Survey's Geologic Names Committee was held on January 10, 1979, to discuss Cretaceous stratigraphic nomenclature to be used in west-central New Mexico. The consensus of those attending the meeting was that "Tres Hermanos" would be retained by geologists, even though its first usage was vague, and would probably be used by other workers even if abandoned by the U.S. Geological Survey. Therefore, the revision of the Tres Hermanos is both appropriate and desirable.

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We also thank Shell Oil Company for permission to publish many sections that Molenaar measured while with Shell. The reconnaissance geologic map of the Puertecito area was begun by Hook and George Bachman, then with the U.S. Geological Survey, in 1977, and finished by Hook and Gary Massingill, then with the New Mexico Bureau of Mines and Mineral Resources. Finally, we owe a profound debt of gratitude to the work of C. L. Herrick, W. S. Pike, Jr., and C. H. Dane, all of whom helped lay the foundation for this paper.

Scope of Tres Hermanos Formation

In placing a stratigraphic top on the Tres Hermanos, Hook and Cobban (1979, fig. 5) and Cobban and Hook (1979a, fig. 3A; 1979b) had to interpret Herrick's description of the type area in light of the stratigraphic framework and concepts of 1900. At that time, Cretaceous rocks were thought to have been deposited as continuous sheets and, therefore, could be correlated like so many layers in a cake.

Herrick's concept of Cretaceous stratigraphy (Herrick and Johnson, 1900, p. 13-15) was based upon extensive work in the Rio Puerco valley, west of Albuquerque, where:

> No single exposure affords an opportunity to measure the thickness of the Cretaceous in our region but the sequence has been pretty well made out. At the bottom is a well-defined bed of granular sandstone . . . [that] attains a thickness of from 25 to 50 feet. . . . The basal sandstone is followed by a series of dark, sometimes lignitic shales with a thickness of over forty feet which near the top contain bands of flags or sandstone impregnated with iron. Usually one of these layers at least is fossiliferous and has been termed the Gasteropod zone. . . . About ten feet of flags follow the dark shales, which are followed by about 75 to 100 feet of yellowish gray shales passing upward

into yellow sandstone about 75 feet thick. In the lower layers of sandstone or in the upper sandy part of the shale below it are frequently developed large concretions often with a cement of iron. These concretions may be over four feet in diameter and often become conspicuous objects in the landscape. *They have been found at so many places in the same place in the series that we have come to attach considerable importance to them as a means of identifying horizons.* . . . At the top of this Tres Hermanos sandstone is a rather constant band of pinkish sandstone. . . . Above the sandstone is a large series of very friable sandy shales which are everywhere so readily eroded as to leave their thickness somewhat obscure. They are broken by small layers of ferruginous sandstone which are somewhat fossiliferous affording for the most part broken fragments. In the neighborhood of (sometimes above but oftener below) this series of sandstone layers is a very widely distributed and conspicuous zone of concretions characterized by an abundance of calcite crystals and the occurrence of a plentiful fauna. These calcareous and septarian concretions often abound in large ammonite shells and large species of Pinna and Baculites which weather out in a very good state of preservation. . . . Above the cephalopod zone and the sandy shales overlying it is another large band of dark and yellow earthy shales at least 100 feet thick capped by a massive sandstone perhaps 50 to 75 feet thick. This we have called the Punta de la Mesa sandstone. . . . The Punta de la Mesa sandstone is undoubtedly of Fox Hills age though it has been very incompletely studied. . . . (Emphasis is ours, not Herrick and Johnson's.)

In terms of present-day nomenclature, 1) "The well-defined bed of granular sandstone" is the main body of the Dakota Sandstone; 2) the "dark, sometimes lignitic shales" are part of the Oak Canyon Member of the Dakota Sandstone; 3) the "Gasteropod zone" contains a Thatcher fauna (Cobban, 1977, p. 5) and is laterally equivalent to the upper part of the Oak Canyon Member of the Dakota Sandstone; 4) the overlying dark and yellowish-gray shales are laterally equivalent to the Cubero Tongue of the Dakota Sandstone and the Clay Mesa Tongue of the Mancos Shale; 5) the "sandstone with large concretions" is the Paguate Tongue of the Dakota Sandstone; 6) the "friable sandy shales" unit is a tongue of Mancos Shale that is equivalent to the Whitewater Arroyo Tongue of the Mancos Shale and the Twowells Tongue of the Dakota Sandstone; 7) the "cephalopod zone" and "series of sandstone layers" are laterally equivalent to the Semilla Sandstone Member of the Mancos Shale; 8) the "large band of dark and yellow earthy shales" is a tongue of Mancos Shale in part equivalent to the D-Cross Tongue; and 9) the "Punta de la Mesa sandstone" is the Gallup Sandstone.

The key correlatable units in Herrick's stratigraphic framework were 1) the "Gasteropod zone," 2) a sandstone with huge concretions (the Tres Hermanos sandstone), 3) the "cephalopod zone," and 4) the Punta de la Mesa sandstone (which he thought was equivalent to the Fox Hills sandstone to the north). Herrick's (1900) trip through western Socorro and Valencia Counties during December 1899 served to convince him that his main Cretaceous units could be recognized as far south as the Rio Salado valley. Herrick (1900, p. 341) explicitly stated that

East of Tres Hermanos . . . *The same sequence is observed at this place as near Albuquerque.* . . . The Dakota sandstone *appears* to be absent and the *so-called* gasteropod zone is within a hundred feet of the bottom, with fossils of Fort Benton age, followed by a band of sandstone with enormous concretions. After a series of soft shales the zone of cephalopods appears and then the Fox Hills sandstone with their large marine assemblage. . . . (Our emphasis.)

Based on Herrick's (1900) description of his journey up Alamosa Creek (Rio Salado) and his sketch map (Herrick, 1900, pl. IX), the "Tres Hermanos" are the Tres Hermanos Peaks shown in sec. 26, T. 3 N., R. 7 W., on the Table Mountain $7^1/2$-min quadrangle. Herrick's description of geology "east of Tres Hermanos" exactly matches the geology in the west half of the Puertecito 7 1/2-min quadrangle (fig. 2), where Herrick's sketch map indicates he was.

In the northwest portion of the Puertecito quadrangle (fig. 2), the dip slope of the Dakota is steep, tree covered, and breeched, allowing red alluvium from the Chinle Formation (Triassic) to mask the Mancos Shale. From a distance these

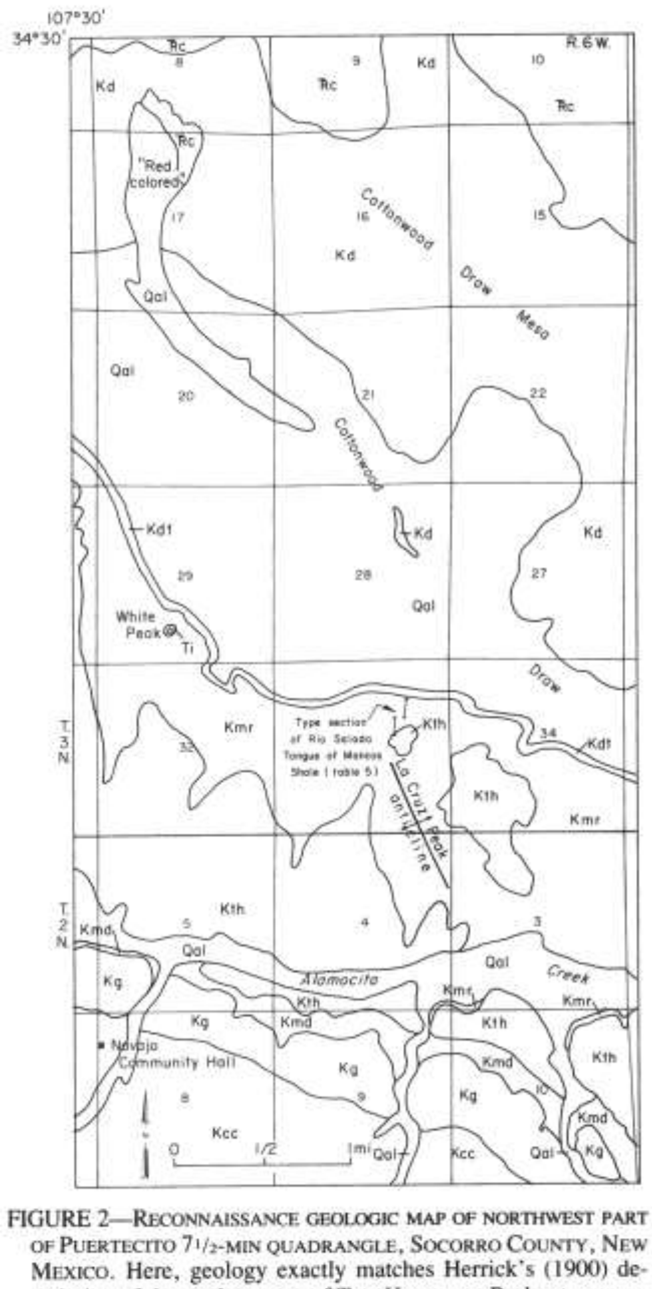

FIGURE 2—Reconnaissance geologic map of northwest part of Puertecito $7^1/_2$-min quadrangle, Socorro County, New Mexico. Here, geology exactly matches Herrick's (1900) description of the geology east of Tres Hermanos Peaks, type area of Herrick's Tres Hermanos Sandstone. Formational contacts are generalized: Triassic Chinle Formation, (**Ꞧc**); Dakota Sandstone, (**Kd**); lower part of Mancos Shale (**Kmi**); Twowells Tongue of Dakota Sandstone, (**Kdt**); Rio Salado Tongue of Mancos Shale, (**Kmr**); Tres Hermanos Formation, (**Kth**); D-Cross Tongue of Mancos Shale, (**Kmd**); Gallup Sandstone, (**Kg**); Crevasse Canyon Formation, (**Kcc**), all of Cretaceous age; Tertiary intrusive rocks, (**Ti**); and Quaternary alluvium, (**Qal**).

features combine to give the impression that the Dakota is absent and that the Mancos was deposited on the Chinle. The Twowells Tongue of the Dakota, the lowest sandstone unit intertongued with the Mancos Shale on the Puertecito quadrangle, is thin (less than 20 ft [6 m] thick) and generally unfossiliferous in Cottonwood Draw, prompting Herrick to describe it as the "so-called gasteropod zone." However, the oyster *Pycnodonte newberryi* (Stanton), a fossil of Fort Benton age, occurs in great numbers in calcareous shales at the base of the overlying Rio Salado Tongue of the Mancos Shale. The basal sandstone of the Tres Hermanos is well exposed above the Twowells and contains numerous, large, fossiliferous, sandstone concretions.

Rocks above this basal sandstone crop out in the area south of present-day Alamocita Creek (as shown on the Puertecito 7 1/2-min quadrangle), where Herrick's sketch map also indicates he traversed. The D-Cross Tongue is the only unit containing numerous fossiliferous, ammonite-bearing concretions that Herrick could have correlated with his "cephalopod zone." Herrick's Punta de la Mesa sandstone is the Gallup Sandstone of this report.

Accordingly, Hook and Cobban (1979, fig. 5) and Cobban and Hook (1979a, fig. 3A) placed the upper boundary of the Tres Hermanos at the base of the shale containing the "Cephalopod zone" (the base of the D-Cross Tongue of the Mancos Shale) and the base of the Tres Hermanos at the base of the sandstone containing huge concretions. The Tres Hermanos as defined above is in accord with both Herrick's stratigraphic concepts and his rather vague definition. As such, the Tres Hermanos can be recognized and mapped over a wide area of west-central New Mexico (fig. 1). The geographic limits are discussed later in this report.

That Herrick intended to name a lithologic unit the Tres Hermanos Sandstone is evident from both of his papers dealing with Cretaceous stratigraphy. In Herrick (1900, p. 338), the name "Tres Hermanos sandstone" was applied to a "massive sandstone with large concretions" and in Herrick and Johnson (1900, p. 14), it was also applied to a sandstone with large concretions.

Herrick himself contributed to a great deal of the confusion surrounding the Tres Hermanos when he (mis)correlated the Tres Hermanos of the Rio Salado valley with the Paguate Tongue of the Dakota Sandstone in the Rio Puerco valley. This miscorrelation, however, was clearly the result of prevailing stratigraphic concepts in which the intertonguing relationships of Upper Cretaceous strata were not recognized.

The Tres Hermanos Formation, as revised herein, is a heterogeneous lithostratigraphic unit that contains marine sandstones and shales as well as nonmarine sandstones, shales, and coals. Accordingly, the word sandstone is deleted from its name because of its monolithic connotation and is replaced with the term "formation."

Tres Hermanos Formation

The Tres Hermanos Formation as here revised is a sandstone and shale unit containing minor coal beds. It is a regressive-transgressive wedge of nearshore marine and nonmarine deposits of late early to late Turonian (mid-Cretaceous) age. This clastic wedge separates the lower or middle part of the Mancos Shale in west-central New Mexico into two parts with the Rio Salado Tongue (new name) below and the D-Cross or Pescado Tongue above (figs. 3, 4; sheet 1, in back pocket).

The Tres Hermanos Formation consists of a basal regressive marine sandstone unit, a medial marginal marine to nonmarine shale and sandstone unit, and an upper transgressive marine sandstone unit. Together, these three units make a distinctive, mappable package that can be recognized (and mapped) over a wide area of west-central and southern New Mexico. Figs. 3 and 4 show the outcrop control and distribution and facies trends of the Tres Hermanos in west-central New Mexico. The southwest or landward limit of the Tres Hermanos is, by definition, at the landward pinch-out of the D-Cross and Pescado Tongues (fig. 3; sheet 1A, in back pocket). The seaward limit of the Tres Hermanos is the northeast extent of the sandstone units at the base and top of the formation (fig. 1). Unlike most regressive-transgressive cycles in which the basal regressive sandstone unit merges with the upper transgressive sandstone (if developed), the upper and lower sandstone units of the Tres Hermanos remain separated and become thinner in a seaward direction as the medial nonmarine unit grades directly into marine Mancos Shale. Because the lower and upper sandstone units thin seaward, they do not crop out in all exposures, making it difficult to determine precisely the seaward pinchout of the Tres Hermanos (sheet 1—A, in back pocket; fig. 3).

The three-part division of the Tres Hermanos is present in most areas where the formation is exposed, but in some areas the upper sandstone unit is thin or locally missing. Also, the marginal marine and nonmarine shales and sandstones of the medial unit grade into marine shale around the northern and eastern extents of the Tres Hermanos. This tripartite division of the Tres Hermanos naturally lends itself to subdivision into three members, which we are naming in ascending order: the Atarque Sandstone Member (revised); the Carthage Member (new name); and the Fite Ranch Sandstone Member (new name).

We are designating the outcrop belt of the Tres Hermanos Formation in Tps. 2 and 3 N. and Rs. 5 and 6 W., Socorro County, as the type area of the Tres Hermanos Formation. In addition, we are establishing a principal reference section for the Tres Hermanos in the Carthage area in secs. 8 and 17, T. 5 S., R. 2 E., Socorro County (table 2), and reference sections in the type area in sec. 6, T. 2 N., R. 5 W., Socorro County (table 3), and along Pescado Creek in sec. 5, T. 10 N., R. 17 W., McKinley County (table 4).

Throughout the area of west-central New Mexico shown on sheet 1A and B (in back pocket) and figs. 3 and 4, the Tres Hermanos ranges from 200 to 300 ft (61-91 m) in thickness, except where it grades into the Mancos Shale at its seaward extent. Specific depositional environments of the three members are discussed in a later section of this paper. The Tres Hermanos conformably overlies the Rio Salado Tongue of the Mancos Shale and is conformably to disconformably overlain by the D-Cross Tongue of the Man-

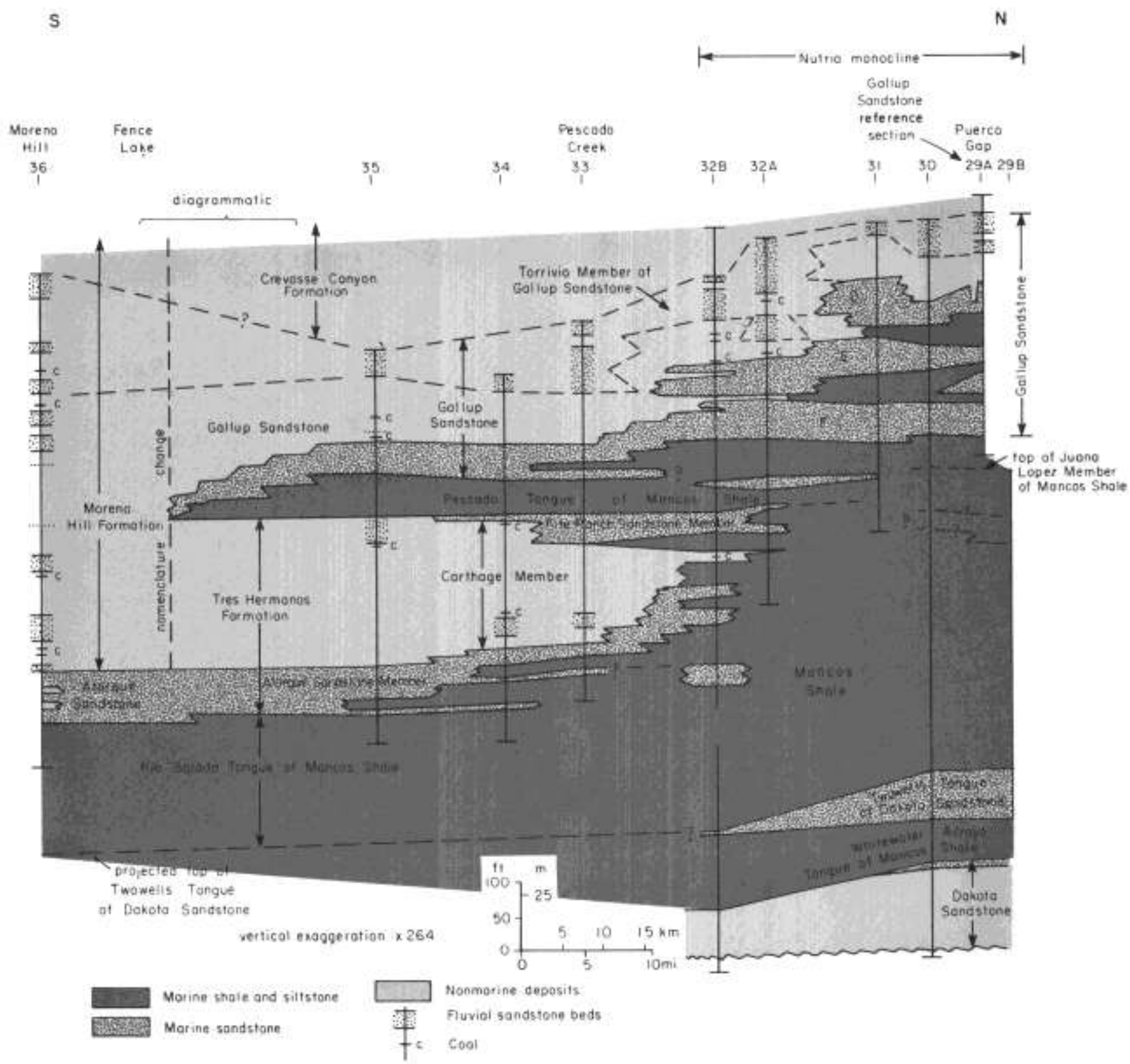

FIGURE 3—STRATIGRAPHIC CROSS SECTION FROM MORENO HILL (CONTROL POINT 36) TO GALLUP (CONTROL POINT 29A) showing stratigraphic relationship in Zuni and southern San Juan Basins (modified from Molenaar, 1973). Stippled patterns represent fluvial sandstone beds and "-c" are coal beds. See fig. 1 for line of section and table 6 for locations of control points.

cos Shale in the eastern part of west-central New Mexico and by the Pescado Tongue of the Mancos Shale in the western part of west-central New Mexico.

At the principal reference section (sheet 1B, control point 59, in back pocket; table 2), the Tres Hermanos Formation is exceptionally well exposed (figs. 5 and 6) and easily accessible. The formation is 277 ft (84 m) thick and consists of 1) a lower 86-ft (26-m)-thick, regressive coastal-barrier sandstone unit (Atarque Sandstone Member); 2) a medial 116-ft (35-m)-thick nonmarine shale and sandstone unit (Carthage Member); and 3) an upper 75-ft (23-m)-thick marine sandstone unit (Fite Ranch Sandstone Member).

The Tres Hermanos Formation has been referred to by other informal or obsolete formal names by previous workers. Pike (1947, p. 35) referred to this interval as the lower part of the Gallup Member of the Mesaverde Formation in the area of Nutria and Pescado Creeks, 30 mi (48 km) south of Gallup, New Mexico. (The Gallup was later raised in rank to a formation of the Mesaverde Group by Beaumont and others, 1956.) Farther south, Pike named the Horsehead Tongue of the Mancos Shale, which he thought was below the marine Pescado Tongue. The sandstones and carbonaceous shales below the Horsehead were called the Atarque Member of the Mesaverde (Pike, 1947, p. 35). Molenaar (1973, p. 94) concluded that what Pike had called the Horsehead Tongue was either some nonmarine, paludal shale in the Atarque or the marine Pescado Tongue. None of Pike's measured sections includes both the Pescado and Horsehead Tongues, and fossils *(Inoceramus dimidius)* collected by Pike from his Horsehead Tongue in his measured section 43 are now known to be confined to the Pescado Tongue. Because of this miscorrelation by Pike, Molenaar (1973, p.

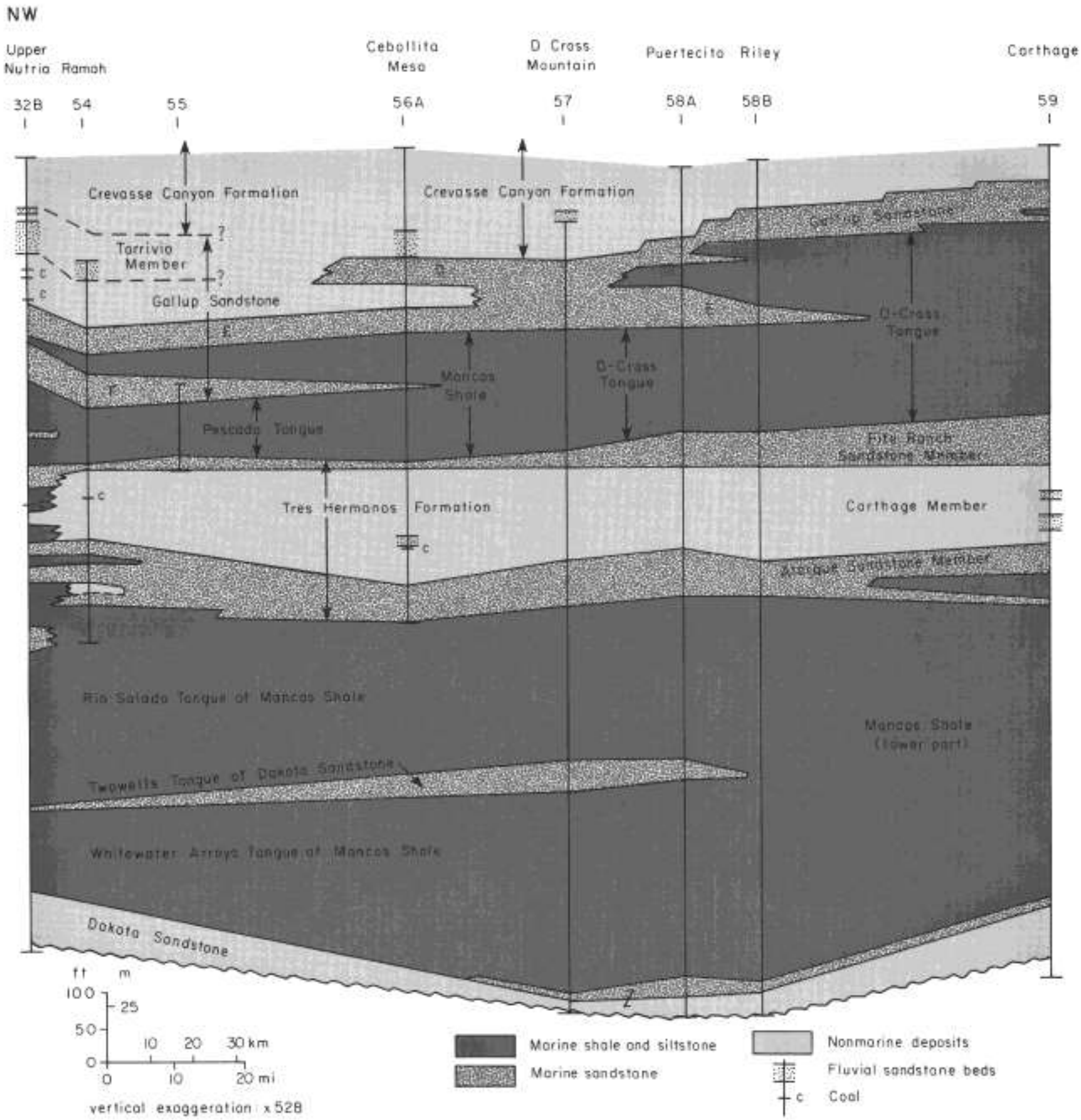

FIGURE 4—Stratigraphic cross section from Upper Nutria (control point 32B) to Carthage (control point 59) showing stratigraphic relationships in Zuni and southern Acoma Basins (modified from Molenaar, 1974). Stippled patterns represent fluvial sandstone beds and "-c" are coal beds. See fig. 1 for line of section and table 6 for locations of control points.

94) suggested that the name Horsehead Tongue be dropped and that the name Atarque Member be applied to the lower part of the Gallup Sandstone of the Mesaverde Formation of Pike (1947). Molenaar then informally referred to the interval we are calling Tres Hermanos Formation as lower Gallup or Atarque Member on his regional correlation sections (Molenaar, 1973, 1974).

We concur with Molenaar's (1973) suggestion that the Horsehead Tongue of the Mancos Shale be abandoned as a formal stratigraphic unit. In addition, however, we recommend removing the lower Gallup or Atarque Member of previous workers from the Gallup and including these strata in the Tres Hermanos Formation because 1) these rocks were deposited during an earlier regressive-transgressive cycle than the cycle during which the Gallup Sandstone of the type area was deposited, 2) they are separated from the upper Gallup or Gallup of the type area by a significant transgressive tongue of Mancos Shale (the Pescado Tongue), and 3) they correlate with the Tres Hermanos Formation of the type area of the Rio Salado valley 80 mi (129 km) to the southeast. Consequently, Gallup nomenclature is now restricted to sandstones overlying or intertonguing with the D-Cross and Pescado Tongues of the Mancos Shale (sheet 1, in back pocket; see Molenaar, this volume).

TABLE 2—PRINCIPAL REFERENCE SECTION OF TRES HERMANOS FORMATION AND TYPE SECTIONS OF FITE RANCH SANDSTONE AND CARTHAGE MEMBERS, SE1/4 SE1/4 sec. 8 and NE1/4 NE1/4 sec. 17, T. 5 S., R. 2 E., San Antonio 15-min quadrangle, Socorro County, New Mexico. Measured April 25, 1980, by C. M. Molenaar using Jacob's staff and Brunton compass.

Unit	Lithology	Thickness ft	Thickness m
	Base of D-Cross Tongue of Mancos Shale		
	Fite Ranch Sandstone Member of Tres Hermanos Formation:		
25	Sandstone, rusty-brown weathering, lower fine-grained, poorly bedded, moderately to well sorted; interstitial clay; fossiliferous, burrowed. This unit forms prominent rusty dip slope in area.	9	2.7
	USGS Mesozoic locality D11161 (from upper 1 ft of unit 25): *Lopha sannionis* (White) *Homomya* sp. *Coilopoceras inflatum* Cobban and Hook *Prionocyclus macombi* Meek (late form)		
24	Sandstone, brown-weathering, lower fine-grained, flat-bedded; ripple marks; common burrows. Lower half is resistant; upper half is slope former.	7	2.1
23	Sandstone, brown-weathering, upper very fine grained, slope-forming.	5	1.5
22	Sandstone, light-gray to light-brown, lower fine-grained, flat-ripple-bedded in beds 2–8 inches thick, moderately sorted; interstitial clay. Unit is resistant ridge former.	7	2.1
21	Sandstone; broken outcrop-slope-forming unit; brown-weathering, upper very fine to lower fine-grained, moderately sorted.	17	5.2
20	Sandstone, brown-weathering, very fine grained at base grading upward to lower fine-grained at top, moderately sorted to well-sorted, bioturbated and burrowed, fossiliferous. *Lopha bellaplicata* common.	14	4.2
19	Siltstone to lower very fine grained sandstone, light-brown-weathering.	6	1.8
18	Sandstone, brown-weathering, lower very fine grained, poorly bedded, burrowed; common *Lopha bellaplicata*.	2	.6
	USGS Mesozoic locality D10354 (from units 18–20): *Lopha bellaplicata novamexicanum* Kauffman *Coilopoceras colleti* Hyatt *Prionocyclus macombi* Meek (early form)		
17	Siltstone to lower very fine grained sandstone, as above.	8	2.4
	Total thickness of *Fite Ranch Sandstone Member* (rounded)	75	22.7
	(Fite Ranch Sandstone is all marine and is associated with a marine transgression.)		
	Carthage Member of Tres Hermanos Formation:		
16	Shale, broken outcrop or partially covered, silty, dark-gray with purplish hue where weathered, nonfissile; carbonaceous fragments; bentonitic.	40	12.1
15	Sandstone, partially covered, fine-grained; probably interbedded with shale in covered zones; petrified wood common in float in upper half.	11	3.3
14	Sandstone, light-gray, upper fine-grained grading upwards to lower fine-grained, crossbedded (currents trending north-northeast to east); clay clasts and wood fragments. (This is a fluvial-channel sandstone.)	3	.9
13	Covered interval of silty claystone, light-gray-green-weathering.	3	.9
12	Siltstone grading up to lower very fine grained sandstone, light-brown to buff-weathering, very slightly calcareous, bioturbated.	2	.6
11	Covered interval of claystone, tan-weathering, noncalcareous.	10	3
10	Sandstone, light-brown-weathering, lower very fine grained, noncalcareous.	1	.3
9	Mostly covered claystone, light-gray-green with some reddish-weathering.	6	1.8
8	Sandstone, partially covered back-slope, lower to upper fine-grained, moderately sorted; common clay clasts.	12	3.6
7	Sandstone, buff, upper fine-grained at base grading to lower fine-grained above, crossbedded (current trending east), moderately sorted; common clay clasts; some wood fragments; interstitial clay. (This is a fluvial-channel sandstone.)	8	2.4
6	Mostly covered—could dig out claystone and siltstone; light-tan-weathering.	7	2.1
5	Sandstone, yellow-buff-weathering, upper very fine grained, crossbedded (current trending east), well-sorted. Unit is lenticular.	3	.9
4	Mostly covered—could dig out dark-gray shale-claystone and siltstone.	10	3
	Total thickness of *Carthage Member* (rounded)	116	35.2
	(Carthage Member is interpreted to be a nonmarine coastal-plain or delta-plain deposit.)		
	Atarque Sandstone Member of Tres Hermanos Formation:		
3	Sandstone, light-gray to brown-weathering, lower very fine grained in upper part, flat-bedded, burrowed; (*Ophiomorpha* in top few feet); root casts in top surface. (This is a regressive coastal barrier or beach.)	44	13.3
2	Partially covered slope-forming unit of siltstone and lower very fine grained sandstone, brown-weathering. (This is a minor transgressive unit.)	27	8.2
1	Sandstone, brown-weathering, lower very fine grained, grading upward to very fine grained, flat-bedded, moderately sorted to well-sorted, calcareous; top is very calcareous; common bivalves. (This is lower shoreface.)	15	4.5
	USGS Mesozoic locality D10241: *Modiolus* sp. *Pinna* sp. *Mytiloides subhercynicus* (Seitz) *Lopha* sp. *Pleuriocardia (Dochmocardia)* n. sp. *Cymbophora emmonsi* (Meek) *Veniella mortoni* Meek and Hayden *Laternula lineata* (Stanton) *Gyrodes depressa* Meek *G. conradi* Meek *Pyropsis coloradoensis* Stanton *Baculites yokoyamai* Tokunaga and Shimizu		

TABLE 2 (con't)

Unit	Lithology	Thickness ft	*m*
	Collignoniceras woollgari woollgari (Mantell)		
	Spathites rioensis Powell		
	Total thickness of *Atarque Sandstone Member* (rounded).	86	*26.1*
	(Atarque Sandstone Member is a regressive coastal-barrier complex.)		
	Total thickness of *Tres Hermanos Formation* (rounded).	277	*83.9*
	Top of *Mancos Shale* (lower part) below.		

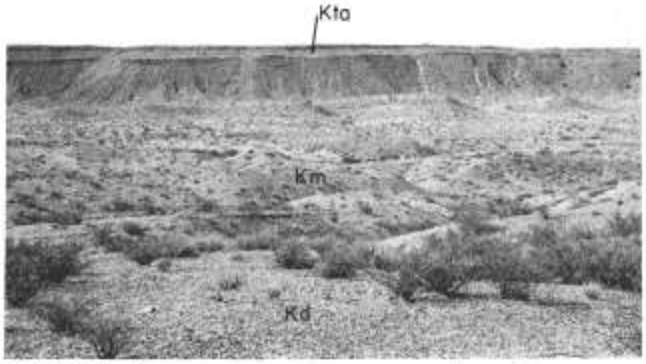

FIGURE 5—PHOTOGRAPH OF LOWER PART OF UPPER CRETACEOUS ROCKS EXPOSED AT CARTHAGE, NEW MEXICO. Dipslope in foreground is developed on Dakota Sandstone **(Kd)**, soft slope-forming unit is lower part of Mancos Shale **(Km)**, double ridge of sandstone at skyline is basal part of Atarque Sandstone Member of Tres Hermanos Formation **(Kta)**. Double row of low hills in background below Atarque Sandstone Member is held up by limestones in Bridge Creek Limestone Beds of Mancos Shale. View is southeast in NW¼ SE¼ sec. 8, T. 5 S., R. 2 E., San Antonio 15-min quadrangle, Socorro County, New Mexico.

TABLE 3—REFERENCE SECTION OF TRES HERMANOS FORMATION FOR TYPE AREA, RIO SALADO VALLEY, NW¼ sec. 6, T. 2 N., R. 5 W., Puertecito 7½-min quadrangle, Socorro County, New Mexico. Measured October 2, 1969, by C. M. Molenaar and B. A. Black using Jacob's staff and Brunton compass.

Unit	Lithology	Thickness ft	*m*
	Top of Tres Hermanos Formation; base of D-Cross Tongue of Mancos Shale.		
	Fite Ranch Sandstone Member of Tres Hermanos Formation		
12	Sandstone, buff, lower very fine grained at base grading up to upper lower fine-grained at top, burrowed in upper 30 ft; 6-inch-thick calcareous bed 13 ft above base. (This member is interpreted to be a transgressive barrier bar.)	50	*15.2*
	Total thickness of *Fite Ranch Sandstone Member* (rounded).	50	*15.2*
	Carthage Member of Tres Hermanos Formation:		
11	Shale, gray silty grading up to shaly siltstone; upper 10 ft grades into sandstone above. Outcrop is partly covered. (Back barrier—nonmarine.)	33	*10*
10	Shale (70%) and sandstone (30%), partly covered outcrop. Shale, dark-gray to light-gray, carbonaceous at top. Sandstone, very fine grained, thin-bedded; root tubes. (Nonmarine coastal or delta-plain with crevasse-splay sandstones.)	75	*22.7*
9	Siltstone to lower very fine grained sandstone.	1	*.3*
8	Covered, some light-gray shale.	4	*1.2*
7	Sandstone, upper very fine grained. (Lacustrine or splay.)	1	*.3*
6	Covered, some light-gray shale.	7	*2.1*
	Total thickness of *Carthage Member* (rounded).	121	*40.3*
	(Carthage Member is interpreted to be a nonmarine, coastal- or delta-plain, low-energy deposit.)		
	Atarque Sandstone Member of Tres Hermanos Formation:		
5	Sandstone; weathers buff to orange; upper very fine grained at base grading up to fine-grained		

FIGURE 6—A) PHOTOGRAPH OF TRES HERMANOS FORMATION SHOWING UPPER PART OF ATARQUE SANDSTONE MEMBER **(Kta)**, MEDIAL CARTHAGE MEMBER **(Ktc)**, AND UPPER FITE RANCH SANDSTONE MEMBER **(Ktf)** at Carthage, New Mexico. Upper part of D-Cross Tongue of Mancos Shale **(Kmd)** and Gallup Sandstone **(Kg)** are exposed in right background. Note sharp contact between Atarque Sandstone and Carthage Members. View is south in SE¼ SE¼ sec. 8, T. 5 S., R. 2 E., San Antonio and Carthage 15-min quadrangles, Socorro County, New Mexico.

FIGURE 6—B) PHOTOGRAPH OF UPPER PART OF CARTHAGE MEMBER **(Ktc)** AND LOWER PART OF FITE RANCH SANDSTONE MEMBER **(Ktf)** AT CARTHAGE, NEW MEXICO, SHOWING GRADATIONAL NATURE OF CONTACT BETWEEN THE TWO MEMBERS. Knob of Fite Ranch Sandstone Member to right of center is at extreme right side of 6A. D-Cross Tongue of Mancos Shale **(Kmd)** and Gallup Sandstone **(Kg)** are visible in background in upper left. View is south in NE¼ NE¼ sec. 17, T. 5 S., R. 2 E., San Antonio and Carthage 15-min quadrangles, Socorro, County, New Mexico.

TABLE 3 (con't)

Unit	Lithology	Thickness ft	m
	at top, crossbedded in upper few feet; fossil hash in lower few feet; burrows in upper part.	32	*9.7*
4	Covered bench, some gray shale.	5	*1.5*
3	Sandstone, buff, upper very fine grained, thin-bedded; calcareous fossiliferous zones.	8	*2.4*
2	Sandstone, upper very fine grained, crossbedded (currents trending northwest, some opposed), ripple-marked; some interference ripple marks; some burrows; interstitial clay.	11	*3.3*
1	Sandstone, lower very fine grained, flat-bedded; minor burrows; interstitial clay.	10	*3*
	USGS Mesozoic locality D10268:		
	Pleuriocardia (Dochmocardia) n. sp.		
	Aphrodina sp.		
	Psilomya concentrica (Stanton)		
	Collignoniceras woollgari woollgari (Mantell)		
	Total thickness of *Atarque Sandstone Member* (rounded).	66	*20*
	(Atarque Sandstone is interpreted to be a regressive coastal-barrier sandstone.)		
	Total thickness of *Tres Hermanos Formation* (rounded).	237	*71.8*
	Top of *Rio Salado Tongue* of Mancos Shale.		

TABLE 4—Reference section of Tres Hermanos Formation and principal reference section of Atarque Sandstone Member for Zuni Basin area, NW1/4 NE1/4 sec. 5, T. 10 N., R. 17 W., Horsehead Canyon NW 7 1/2-min quadrangle, McKinley County, New Mexico. Measured April 16, 1980, by C. M. Molenaar and S. C. Hook using Jacob's staff and Brunton compass.

Unit	Lithology	Thickness ft	m
	Base of Pescado Tongue of Mancos Shale		
	Fite Ranch Sandstone Member of Tres Hermanos Formation:		
21	Sandstone, buff-weathering, lower fine-grained, very well sorted, porous, flat-bedded with zones of medium-scale (6 inch ±) crossbeds (currents trending west and northwest); prominent cliff former.	23	*7.*
20	Sandstone, light-gray, buff-weathering, very fine grained (no sequence), flat-bedded with minor low-angle crossbeds in lower 5 ft; abundant burrowing and bioturbation in upper 20 ft. (This and above sandstone unit are associated with a marine transgression.)	25	*7.6*
	Total thickness of *Fite Ranch Sandstone Member* (rounded).	48	*14.6*
	Cathage Member of Tres Hermanos Formation:		
19	Covered soft section, probably mostly shale and siltstone, with carbonaceous shale in middle. (This is a nonmarine, paludal sequence.)	44	*13.3*
18	Sandstone, light-gray, buff-weathering, very fine grained grading upwards to lower fine-grained; abundant vertical burrows. (Paludal-lacustrine environment.)	9	*2.7*
17	Covered soft section, some gray, noncarbonaceous shale in upper part. Also		

TABLE 4 (con't)

Unit	Lithology	Thickness ft	m
	about 10% thin-bedded very fine grained sandstone. (Nonmarine.)	45	*13.6*
16	Sandstone, gray, upper very fine grained, burrowed, and bioturbated; common carbonaceous fragments. (Paludal-lacustrine environment.)	3	*.9*
15	Covered soft section, dug out silty shale and siltstone.	4	*1.2*
14	Sandstone, light-gray, buff-weathering, upper-fine-grained at base grading upward to lower fine-grained at top, medium-scale crossbedded (current trending east); abrupt basal contact; common clay clasts in lower 1 or 2 ft; noncalcareous; bold ledge former. (This is a fluvial-channel sandstone.)	20	*6.1*
13	Sandstone, gray, very fine to fine with minor upper fine-grained (no sequence), flat-bedded, highly burrowed and bioturbated; common carbonaceous fragments; porous. (This is a splay sandstone.)	8	*2.4*
12	Partially covered carbonaceous shale.	11	*3.3*
11	Sandstone, very fine grained, burrowed and bioturbated; gradational contact with shale below. (This is a splay sandstone.)	3	*.9*
10	Shale, carbonaceous, paludal, mostly covered.	5	*1.5*
	Total thickness of *Carthage Member* (rounded). (Carthage Member is interpreted to be a nonmarine, back-barrier, coastal-plain or delta-plain deposit.)	152	*46.1*
	Atarque Sandstone Member of Tres Hermanos Formation:		
9	Sandstone, buff, very fine grained, grading upwards to lower fine-grained at top, flat-bedded to massive in lower half, crossbedded above (currents trending west to southwest); minor burrows; root casts on top surface; abrupt basal contact with underlying shale. (This is a back-barrier tidal washover sandstone or represents a minor transgression of the coastal barrier over lagoonal or bay sediments.)	14	*4.2*
8	Partially covered soft section of shale, dark-gray, and 25% sandstone, very fine grained in beds 1–2 ft thick. (Probably lagoon or bay deposits.)	11	*3.3*
7	Sandstone, buff, very fine grained, flat-bedded; vertical burrows; clay clasts; ledge former.	2	*.6*
6	Covered.	3	*.9*
5	Sandstone, buff, upper very fine grained, flat-bedded.	1	*.3*
4	Covered soft section, dug out dark-gray claystone and siltstone.	5	*1.5*
3	Sandstone, buff-weathering, very fine grained grading upward to lower fine-grained, flat-bedded to massive except medium-scale low-angle crossbeds in top 3 ft, slightly calcareous; top foot is more calcareous and weathers dark-brown; interstitial clay; small pelecypods; ledge former.	9	*2.7*
2	Covered soft section, dug out sandy siltstone.	10	*3*
1	Sandstone, light-gray-green-weathering, very fine grained, platy with some low-angle crossbeds; interstitial clay; common pelecypod fragments.	3	*.9*
	USGS Mesozoic locality D11140:		
	Spathites sp.		

TABLE 4 (con't)

Unit	Lithology	Thickness ft	m
	Total thickness of *Atarque Sandstone Member* (rounded).	58	17.6
	(Total interval represents a low-energy regression from shallow open-marine shale below to back-barrier and nonmarine deposits of Carthage Member above.)		
	Total thickness of *Tres Hermanos Formation* (rounded).	258	78.2
	Rio Salado Tongue of Mancos Shale:		
	Covered, could dig out siltstone and silty shale	12	3.6
	Concretion zone, brown-weathering.	2	.6
	Partially covered shale, dark-gray, silty.	10	3
	Total thickness of *Rio Salado Tongue* (incomplete section—no outcrops below).	24	7.3

Atarque Sandstone Member

In the area south of Pescado Creek, Pike (1947, p. 35) applied the name Atarque Member of the Mesaverde Formation (subsequently elevated to group status) to what he thought was a different unit than his lower Gallup in the same area. Subsequent work by Molenaar (1973, p. 94) has shown that these two units are the same and that the Horsehead Tongue of the Mancos Shale, which Pike named for a shale tongue that he thought separated the two units, was the result of a miscorrelation or misidentification. By our definition, these strata are now included in the Tres Hermanos Formation. In order to preserve the usage of the Atarque Member, we are revising it by restricting the term to the lower sandstone unit of the Tres Hermanos. The name was taken from the now-abandoned community of Atarque, 55 mi (88 km) south of Gallup. Because of poor exposures and much slumping in the area where Pike originally applied the name (near Horsehead Canyon in the SW 1/4 sec. 32, T. 10 N., R. 17 W.), we are designating a principal reference section for the Atarque a few miles farther north along the north side of Pescado Creek in the NW 1/4 NE 1/4 sec.5, T. 10 N., R. 17 W. (our control point 33 and table 3). This is near Pike's section 40, the type section for the Pescado Tongue. (We are also designating this section as a reference section for the Tres Hermanos Formation in the Zuni Basin.) The Atarque is not as well developed at that section as in some areas, but exposures are good and the area is readily accessible.

The Atarque Member is a regressive coastal-barrier sandstone or shoreface complex that prograded northeastward into the Mancos seaway. At the principal reference section, the Atarque is 58 ft (18 m) thick, although the lower three-fourths is transitional and consists of intertonguing shale, siltstone, and thin beds of sandstone. At the principal reference section of the Tres Hermanos near Carthage, the Atarque is 86 ft (26 m) thick and is dominantly sandstone. Detailed descriptions of three reference sections of the Tres Hermanos are included in tables 2, 3, and 4. Throughout the area, the Atarque ranges in thickness from as little as 8 ft (2.4 m) to almost 100 ft (30 m). Sheet 1 (in back pocket) and figs. 3 and 4 show some of these variations. The thicker sections, as at the principal reference section, are commonly multicyclic; individual regressive shoreface buildups are usually no thicker than 20 ft (6 m) in the Nutria—Fence Lake area on the west but range to 40-50 ft (12-15 m) thick in the eastern areas. These regressive sandstones are usually light gray on fresh exposure but weather brown or buff. They are coarsening-upward sequences ranging in texture from very fine to lower fine grained and contain much interstitial clay. The bedding is generally planar although minor medium-scale crossbeds do occur. Scattered burrows, including *Ophiomorpha,* also are common, and locally bioturbated zones are present. In many places, what are interpreted to be tidal channel sandstones are more common than regressive shoreface sandstones. These sandstones are generally highly crossbedded, and locally the crossbed dip directions are opposed. The textures usually grade from fine or upper fine grained at the base to very fine grained at the top. Clay clasts are locally present in the lower part and burrows are common.

The Atarque Member is interpreted to have been deposited along a relatively low-energy shoreline adjacent to a very shallow seaway. Wave energy was not great and tidal currents were an important depositional process. The shoreline was probably very digitate and embayed as indicated by the ranges in thickness and variations of shoreline sandstone units. The Atarque is probably the result of nondeltaic coastal progradational processes although in some local areas deltaic processes were dominant.

The Atarque Member is a diachronous unit that becomes younger from southwest to northeast. The seaward part of the Atarque is probably equivalent to the Semilla Sandstone Member of the Mancos Shale, an offshore sandstone deposit on the southeast side of the San Juan Basin (Dane and others, 1968; Molenaar, 1974, 1977; La Fon, 1981). To the southwest (landward) in the Fence Lake area, the Atarque is of formation rank and lies between the Rio Salado Tongue below and the Moreno Hill Formation (McLellan and others, this volume) above.

Carthage Member

The Carthage Member is the medial, marginal marine and nonmarine shaly part of the Tres Hermanos Formation. The member is named for the abandoned coal-mining community of Carthage approximately 16 mi (25 km) southeast of Socorro. The type section, about 116 ft (35 m) thick, is in the SE 1/4 SE 1/4 sec. 8 and NE 1/4 NE 1/4 sec. 17, T. 5 S., R. 2 E. There the Carthage Member contains several sandstone beds in the lower two-thirds. These beds generally are thin and are either very fine grained paludal-lacustrine or crevasse-splay, bay-fill types of sandstone, or thin discontinuous fine-grained crossbedded channel sandstones. Two mi (3 km) to the east, these sandstones are only a minor constituent. The shales and siltstones of the Carthage Member are dark gray but weather light green to purplish. Carbonaceous to coaly shales are present but not abundant. A detailed description is included in table 2.

Throughout west-central New Mexico, the Carthage Member ranges in thickness from about 100 to 225 ft (30 to 68 m). Thin coal beds occur in some areas, especially in the western Acoma Basin and the southern Zuni Basin. None of the coal beds appear to be thicker than 2 ft (0.6 m), although no attempt was made to trench the outcrops. The coal beds noted are shown on the individual measured sections on the correlation sections (sheet 1, in back pocket; figs. 3 and 4).

Distributary or fluvial channel sandstones are common in the western part of the area south of Pescado Creek but are less common and thinner east of Acoma Basin. These sandstones are lenticular, and individual channel sandstones are usually less than 25 ft (7.5 m) in thickness. Most sandstones are fine grained; locally they coarsen to lower medium grained. Interstitial clay is common. The fluvial channel sandstones are shown on the individual control points on the correlation sections (sheet 1; figs. 3 and 4).

The Carthage Member does not thin uniformly toward its seaward limit as is the case with most Upper Cretaceous nonmarine wedges. Instead, the nonmarine paludal shales grade directly into marine shales of the Mancos as shown on the correlation sections (sheet 1; figs. 3 and 4). A few thin sandstone beds are common in this transitional zone. The underlying and overlying coastal marine sandstone units (Atarque and Fite Ranch Sandstone Members) do not converge to form the classic regressive-transgressive wedge.

Deposition of the Carthage Member is interpreted to have been on a broad, very low relief coastal or delta plain. The Atarque shoreline to the northeast was probably highly em-bayed, and in many places the marginal marine bay deposits merge with the paludal marsh deposits. At the seaward margins, where the nonmarine muds grade directly into open marine muds of the Mancos, the seaway must have been very shallow and, as a result of very low wave energy combined with a probably low sand content of the few distributaries, shoreface or beach sands were not deposited. This type of shoreline transition is not common in most of the Upper Cretaceous sequences in the Western Interior seaway.

Fite Ranch Sandstone Member

The name Fite Ranch Sandstone Member is herein applied to the upper sandstone unit of the Tres Hermanos Formation.The member is named for Fite Ranch, which is approximately 1 mi (1.6 km) south of the abandoned coal mining community of Carthage. The type section is in the NE 1/4 NE'/4 sec. 17, T. 5 S., R. 2 E. A detailed description of the type section is given in table 2. The Fite Ranch Member is a well-developed coastal-barrier sandstone 75 ft (23 m) thick at the type section, but it is much thinner in most other areas and is locally absent (sheet 1A and B, in back pocket; figs. 3 and 4). The sandstones are light gray but weather light to medium brown and generally consist of a coarsening-upward sequence ranging from very fine grained at the base to lower fine grained at the top. Upper fine to medium grains commonly occur either at the contact with, or scattered in, the basal foot (30 cm) of the overlying transgressive D-Cross or Pescado Tongue of the Mancos Shale. Interstitial clay is common but not as prevalent as in the Atarque Member. Planar bedding predominates but is generally obscured by burrowing and bioturbation.

The Fite Ranch Sandstone Member is a coastal-barrier sandstone associated with the overlying transgressive D-Cross or Pescado Tongue of the Mancos Shale. At the type section and a few other areas in the southeast Acoma Basin and farther east, the Fite Ranch is thick and has a gradational base with a 10-15-ft (3-4.5-m)-thick section of locally fossiliferous silty shales or very fine grained sandstone resting on the Carthage Member. The oyster *Lopha bellaplicata* (Shumard) in this basal zone in some areas indicates a normal marine environment, which suggests that the top of the Carthage Member or base of the Fite Ranch Sandstone Member at those areas represents a transgression followed by an offlap or regression during which the major part of the Fite Ranch was deposited. In areas farther west, sandstone of the Fite Ranch overlies nonmarine coaly or carbonaceous shale deposits with a sharp contact. In those areas the unit generally is thin, commonly 10-15 ft (3-4.5 m) thick or less. These sequences are interpreted to represent a barrier complex that transgressed its back-barrier lagoonal or coal-swamp deposits. This type of transgression has been described in Holocene deposits of the Atlantic and Gulf Coasts (Kraft and John, 1979). A more detailed study of the Fite Ranch Sandstone Member is necessary to decipher its complex depositional history more precisely.

Near its seaward limit, the Fite Ranch Member becomes thinner and probably discontinuous. Because the underlying nonmarine Carthage Member grades to marine Mancos Shale and also contains thin sandy zones at the transition, recognition of the Fite Ranch is difficult and use of the term is probably unwarranted in those areas.

Age

The Tres Hermanos Formation ranges in age from late early to early late Turonian in west-central and southern New Mexico. The oldest fossils collected from the basal part of the Atarque Sandstone Member have come from the Love Ranch area, 20 mi (32 km) northeast of Las Cruces, and include *Mammites nodosoides* (Schluter) of late early Turonian age (fig. 7). The youngest fossils from the Atarque have come from the Paradise Canyon area, 7 mi (11 km) southwest of Acoma Pueblo, near the pinchout point of the Tres Hermanos, and include *Collignoniceras woollgari regulare* (Haas)? and *Spathites chispaensis* Powell, which are indicative of an early middle Turonian age. To the west, *Spathites puercoensis* (Herrick and Johnson), indicative of the *Prionocyclus hyatti* Zone of late middle Turonian age, was collected from the base of the undifferentiated Tres Hermanos Formation in the Black Creek valley, approximately 10 mi (16 km) south of Window Rock, Arizona.

The age of the normally nonmarine Carthage Member is usually based on the ages of overlying and underlying members of the Tres Hermanos. On this basis, the Carthage Member ranges in age from late early to late Turonian. However, the marine oyster *Lopha bellaplicata* (Shumard) has been collected from the upper part of the Carthage Member in the Jornada del Muerto coal field (Tabet, 1979, p. 14). The marine shale from which this collection was made is associated with the overlying Fite Ranch—D-Cross transgression. *Lopha bellaplicata* occurs in the *Prionocyclus hyatti* Zone and in the basal part of the overlying *Prionocyclus macombi* Zone and, therefore, has an age range of late middle to earliest late Turonian.

The Fite Ranch Sandstone Member is diachronous and becomes younger to the south. However, in the area of west-central New Mexico that includes the Acoma Basin, Carthage, Oscura, and Truth or Consequences, the top of the Fite Ranch appears to be virtually synchronous. In those areas the ammonite *Coilopoceras inflatum* Cobban and Hook occurs either in the upper few feet of the member or in the basal few feet of the overlying D-Cross Tongue of the Man-cos Shale. Other fossils often occurring with *C. inflatum* include *Prionocyclus macombi* Meek (late form), *Lopha lugubris* (Conrad), and *Inoceramus dimidius* White. The

Stage		Zone	Subzone
Turonian	upper	*Prionocyclus quadratus*	
		Prionocyclus novimexicanus	
		Prionocyclus wyomingensis	*Scaphites ferronensis*
			Scaphites warreni
		Prionocyclus macombi	*Coilopoceras inflatum*
			Coilopoceras colleti
	middle	*Prionocyclus hyatti*	*Coilopoceras springeri*
			Hoplitoides sandovalensis
		Subprionocyclus? percarinatus	
		Collignoniceras woollgari	*Collignoniceras woollgari regulare*
			Collignoniceras woollgari woollgari
	lower	*Mammites nodosoides*	
		Vascoceras birchbyi	
		Pseudaspidoceras flexuosum	
Cenomanian (part)	upper	*Neocardioceras juddii*	
		Vascoceras gamai	
		Sciponoceras gracile	
		Metoicoceras mosbyense	
		Calycoceras canitaurinum	
	middle	*Acanthoceras amphibolum*	*Plesiacanthoceras* aff. *P. wyomingense*
			Acanthoceras amphibolum amphibolum
			Acanthoceras amphibolum alvaradoense
		Conlinoceras tarrantense	

FIGURE 7—AMMONITE ZONES FOR PART OF CENOMANIAN STAGE AND ALL OF TURONIAN STAGE IN NEW MEXICO; all zonal indices have been collected by the authors in New Mexico. The basal middle Cenomanian zone of *Conlinoceras tarrantense* (Adkins) contains the oldest, marine Cenomanian megafauna found in the intertongued Dakota Sandstone–Mancos Shale sequence in New Mexico.

oldest fossils collected from the Fite Ranch Member have come from the base of the member at Carthage and include *Prionocyclus macombi* (early form), *Coilopoceras colleti* Hyatt, and *Lopha bellaplicata novamexicanum* Kauffman of earliest late Turonian age. The youngest fossils from the Fite Ranch Member are two specimens of *Scaphites whitfieldi* Cobban from the Love Ranch area northeast of Las Cruces.

The fossil assemblage found in the upper part of the Fite Ranch Member in the Acoma Basin, and at Carthage, Truth or Consequences, and Oscura, 47 mi (76 km) southeast of Carthage, is identical to that found in the basal part of the Juana Lopez Member of the Mancos Shale (Dane and others, 1966; Hook and Cobban, 1980). A strong time correlation between the two units is indicated.

Disconformity

A disconformable contact between the Tres Hermanos Formation and the overlying D-Cross or Pescado Tongue of the Mancos Shale is suggested by 1) the presence of worn, phosphatized internal molds of fossils and 2) the absence of faunal zones. Evidence for this disconformity is limited so far to only four outcrops.

At Carthage (sheet 1—B, control point 59, in back pocket) the oyster *Lopha sannionis* (White) occurs at the top of the Fite Ranch Sandstone Member in association with *Prionocyclus macombi* Meek (late form) and *Coilopoceras inflatum* Cobban and Hook. *Prionocyclus novimexicanus* (Marcou) occurs in concretions in the D-Cross Tongue approximately 10 ft (3 m) above the top of the Fite Ranch Member. These occurrences indicate that the entire *Prionocyclus wyomingensis* Zone is missing at Carthage because *L. sannionis* is now known to range no lower than the base of the *Prionocyclus novimexicanus* Zone (Hook and Cobban, 1981a). Further evidence of erosion and nondeposition in that area is indicated by phosphatized bivalve molds recovered from the top of the Fite Ranch Member.

On the Sevilleta Grant, 25 mi (40 km) north of Carthage, worn, phosphatized internal molds of bivalves, gastropods, and ammonite chambers occur at the top of the Fite Ranch Member in association with nonphosphatized *Lopha bellaplicata*. Hook and Cobban (1981b) have interpreted a similar occurrence of phosphatized, worn molds in the Bridge Creek Limestone Member of the Colorado Formation in southwest New Mexico as representing an erosional episode in which prefossilized molds were eroded out of soft sediment, concentrated as a lag deposit on the seafloor, and then phosphatized at the sediment-water interface. *Lopha lugubris* (Conrad), *Scaphites warreni* Meek and Hayden, and *Prionocyclus wyomingensis* Meek occur in thin calcarenite beds of Juana Lopez aspect approximately 5 ft (1.5 m) above the phosphatized molds on the Sevilleta Grant. This 5-ft (1.5-m)-thick interval must then represent much of the time associated with the *Prionocyclus macombi* Zone and is condensed relative to the type and reference sections of the Juana Lopez Member of the Mancos Shale. At both the type and reference sections of the Juana Lopez Member, the part of the *Prionocyclus macombi* Zone above the last occurrence of *Lopha bellaplicata* is represented by more than 100 ft (30 m) of section (Dane and others, 1966; Hook and Cobban, 1980).

Similarly, the occurrence of *Lopha lugubris* in the same bed with *Lopha bellaplicata* at the top of the Tres Hermanos Formation in the Zuni Basin (sheet 1—A, control point 32A, in back pocket) and along the Defiance monocline in Arizona also is suggestive of a disconformable relationship.

Characteristic fauna

The most diverse molluscan fauna in the Tres Hermanos Formation occurs in brown-weathering, calcareous sandstone concretions in nearshore, marine sandstones in the basal part of the Atarque Sandstone Member. The noncephalopod portion of this fauna was apparently facies controlled and has been collected from sandstone concretions in the Atarque Member throughout the Acoma and Zuni Basins, at Carthage and the Jornada del Muerto coal field, and on the Sevilleta Grant.

This fauna is so abundant, diverse, and well preserved in these concretions that we have come to regard it as the characteristic fauna of the Tres Hermanos Formation (fig. 8).

The noncephalopod portion of this fauna collected from the Atarque Sandstone Member consists of the following 22

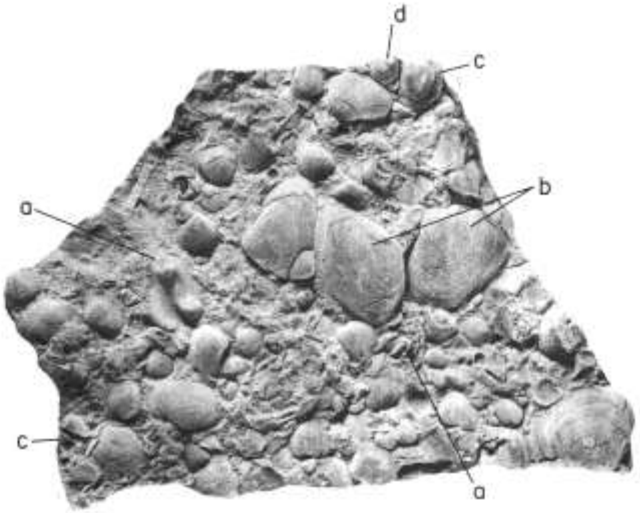

FIGURE 8—CHARACTERISTIC FAUNA (ONE-HALF NATURAL SIZE) OF THE TRES HERMANOS FORMATION PRESERVED ON SLAB OF FINE-GRAINED SANDSTONE CONCRETION FROM BASAL PART OF ATARQUE SANDSTONE MEMBER at USGS Mesozoic locality D10984 in SE corner sec. 22, T. 8 N., R. 17 W., Cibola County, New Mexico. Fragments of *Collignoniceras woollgari woollgari* (a) are preserved in a coquina-like accumulation of *Cymbophora utahensis* (b), *Cymbophora emmonsi* (c), and *Pleuriocardia (Dochmocardia) pauperculum* (d).

bivalves and 9 gastropods (list updated from Cobban and Hook, 1979a, p. 11):

Bivalves:
- *Modiolus* sp.
- *Pinna* cf. *P. guadalupe* Böse
- *Phelopteria gastrodes* (Meek)
- *Pseudoptera* sp.
- *Inoceramus cuvieri* Sowerby
- *Mytiloides mytiloides* (Mantell)
- *M. subhercynicus* (Seitz)
- *Crassostrea soleniscus* (Meek)
- *Ostrea* sp.
- *Lopha* sp.
- *Pleuriocardia (Dochmocardia) pauperculum* (Meek)
- *Cymbophora emmonsi* (Meek)
- *C. utahensis* (Meek)
- *Tellina modesta* Meek
- *Protodonax* sp.
- *Veniella mortoni* Meek and Hayden
- *Aphrodina* sp.
- *Cyprimeria* sp.
- *Legumen ellipticum* Conrad
- *Pholadomya* sp.
- *Laternula lineata* Stanton
- *Psilomya concentrica* (Stanton)

Gastropods:
- *Perissoptera*? sp.
- *Pugnellus (Gymnarus) fusiformis* Meek
- *Gyrodes conradi* Meek
- *G. depressa* Meek
- *Pyropsis coloradoensis* Stanton
- *Tectaplica*? *utahensis* (Meek)
- *Rostellinda dalli* (Stanton)
- *R. ambigua* (Stanton)
- Olividae n. gen. and n. sp.

Landward equivalents

The Tres Hermanos terminology is no longer applicable southwest of the landward pinchout of the Pescado and D-Cross Tongues. The Pescado Tongue pinches out in the area between Fence Lake and Atarque (sheet 1–A, in back pocket, and fig. 3, between control points 35 and 36). We recommend that the basal regressive, marine sandstone—which farther north is the Atarque Sandstone Member of the Tres Hermanos Formation—be called the Atarque Sandstone, a unit of formational rank, southwest of this pinchout point. The nonmarine rocks above the Atarque Sandstone have been named the Moreno Hill Formation by McLellan and others (this volume). Strata of the Moreno Hill Formation are laterally equivalent to the Carthage and Fite Ranch Members of the Tres Hermanos Formation, the Pescado Tongue of the Mancos Shale, the Gallup Sandstone, and the lower part of the Crevasse Canyon Formation (sheet 1–A, in back pocket, and fig. 3; Molenaar, 1973, and this volume).

At our measured section at Moreno Hill (sheet 1, control point 36, in back pocket), which is 1.6 mi (2.6 km) southeast of the type section of the Moreno Hill Formation (McLellan and others, this volume), the Atarque Sandstone is 79 ft (24 m) thick and the Moreno Hill Formation is 622 ft (190 m) thick. The Moreno Hill Formation consists of nonmarine shales and fluvial channel sandstones and contains coal beds as much as 3 ft (1 m) thick in the lower part. The fluvial sandstone unit in the upper 200 ft (61 m) of our measured section is coarser grained than those below and may be equivalent to the Torrivio Member of the Gallup Sandstone (sheet 1–A, in back pocket, and fig. 3; Molenaar, 1973, and this volume).

In areas where the marine shale of the Pescado or D-Cross Tongue pinches out or grades laterally into shoreface sandstone or nonmarine rocks, the stratigraphic nomenclature for the sequence is arbitrary and could be either Atarque Sandstone, Tres Hermanos Formation, or Gallup Sandstone. The terminology for the intertonguing lithologies in these transitional areas, which are probably small, should be chosen by the geologist investigating the area.

Mappability

The Tres Hermanos Formation, as herein revised, has previously been mapped as the middle sandstone member of the Mancos Shale by Wilpolt and Wanek (1951) in eastern Socorro County and as the Tres Hermanos Sandstone Member of the Mancos Shale by Tabet (1979) in the Jornada del Muerto coal field. The Tres Hermanos Formation (as herein revised) has been mapped by personnel from the U.S. Geological Survey in the northern Acoma Basin (S. L. Moore, personal communication, 1981) and by personnel from the New Mexico Bureau of Mines and Mineral Resources in the southern Acoma Basin (Osburn, 1982, 1983). South of the pinchout point of the Pescado Tongue of the Mancos Shale in the southern Zuni Basin, the Atarque Sandstone has been mapped by personnel from the U.S. Geological Survey (McLellan and others, personal communication, 1981) and by personnel from the New Mexico Bureau of Mines and Mineral Resources (Anderson, 1981).

Geographic limits in New Mexico

The Tres Hermanos can be recognized and mapped over a wide area of west-central and southern New Mexico extending from the Love Ranch area northeast of Las Cruces on the south, to Oscura on the east, to Putney Mesa (Mesa Negra) in the northern Acoma Basin, and to the Upper Nutria area of the northern Zuni Basin (sheet 1—A, in back pocket, and fig. 3, control point 32A). South of the pinchout point of the Pescado and D-Cross Tongues of the Mancos Shale, the Tres Hermanos Formation is not recognized and the Atarque Sandstone and Moreno Hill Formation are the stratigraphic names applied. The Pescado Tongue pinches out in surface sections (sheet 1 A, in back pocket, and fig. 3, between control points 35 and 36), and the D-Cross Tongue pinches out in the subsurface far south of the Acoma Basin (fig. 1).

Correlation

The correlations shown on sheet 1 (in back pocket) and figs. 3 and 4 are based on a combination of physical and biostratigraphic factors. These diagrams portray the detailed physical relationships of strata from the Dakota Sandstone through the Gallup Sandstone.

Although the correlation of Tres Hermanos Sandstone with the Twowells Tongue of the Dakota Sandstone was shown to be a case of mistaken identity (Dane and others, 1971), the correlation of the Tres Hermanos Formation with the Gallup Sandstone was the result of several factors. Not the least of these factors is the vertical proximity of the Tres Hermanos to the Gallup in the Zuni Basin, where as little as 50 ft (15 m) of Pescado Tongue separate the two units in some areas. As a result, the Tres Hermanos was either correlated with or included in an expanded definition of the Gallup Sandstone (Molenaar, 1973, 1974). However, our stratigraphic studies have shown that the Pescado and D-Cross Tongues of the Mancos Shale represent a transgressive event of regional significance that warrants separating the Tres Hermanos Formation from the Gallup Sandstone.

One of the more difficult aspects of the biostratigraphic work was to find age-diagnostic fossils in the Pescado Tongue that could be used to correlate the Pescado Tongue with the Mancos Shale in the Gallup, New Mexico, area and with the D-Cross Tongue in the Acoma Basin. A collection of *Inoceramus dimidius* White (Hook and Cobban, 1980, fig. 7) from the middle of the Pescado Tongue in the NE 1/4 NE 1/4 sec. 11, T. 10 N., R. 17 W., 3.6 mi (5.8 km) east-southeast of the type section of the Pescado Tongue, proved to be the key to the correlation. *Inoceramus dimidius* is characteristically found in the lower and upper (but not uppermost) parts of the Juana Lopez Member of the Mancos. The Gallup Sandstone at its type locality near Gallup is stratigraphically above the top of the Juana Lopez Member and, hence, above the uppermost occurrence of *Inoceramus dimidius* (sheet 1A, control points 29A and 29B, in back pocket). The top of the Tres Hermanos Formation in its type area, on the other hand, is temporally equivalent to the base of the Juana Lopez. There, thin calcarenite beds of Juana Lopez aspect that contain *Inoceramus dimidius* occur stratigraphically above the Tres Hermanos (sheet 1—A, control point 58A, in back pocket).

The Tres Hermanos Formation, therefore, was deposited during an earlier regressive-transgressive cycle than the Gallup Sandstone and is separated from the Gallup by the Pescado Tongue in the Zuni Basin and by the D-Cross Tongue in the Acoma Basin. Every subsequent age-diagnostic fossil collection made from either the Pescado or D-Cross Tongue has verified the age difference between the Tres Hermanos and Gallup and has helped substantiate our correlations.

Rio Salado Tongue of Mancos Shale

The shale tongue between the Twowells Tongue of the Dakota Sandstone and the Tres Hermanos Formation (or Atarque Sandstone) is herein named the Rio Salado Tongue of the Mancos Shale. The Mancos Shale of west-central New Mexico above the Twowells Tongue and below the Gallup Sandstone is divided into two parts by the Tres Hermanos Formation. The upper part of the Mancos is called the D-Cross Tongue in the Acoma Basin (Dane and others, 1957) and the Pescado Tongue in the Zuni Basin (Pike, 1947); the lower part was previously unnamed. The Rio Salado Tongue is named for typical exposures along the Rio Salado in northwest Socorro County. The type section of the Rio Salado Tongue is in the NE 1/4 sec. 33, T. 3 N., R. 6 W., Socorro County (fig. 2), and is within the type area of the Tres Hermanos Formation.

The Rio Salado Tongue ranges in thickness from 200 to 300 ft (61-91 m) and is coextensive with both the underlying and overlying units. The contact with the Twowells Tongue is conformable and sharp; the contact with the Tres Hermanos Formation (or Atarque Sandstone) is conformable and ranges from gradational to intertonguing. The Rio Salado Tongue consists of a lower unit of calcareous shale with thin interbeds of limestone and an upper unit of non-calcareous clay shale with numerous fossiliferous or septarian limestone concretions; the two units are of subequal thickness.

At its type section (sheet 1—A, control point 58A, in back pocket), the Rio Salado Tongue is 236 ft (72 m) thick (table 5). The lower calcareous shale and limestone unit is 126 ft (38 m) thick and the upper noncalcareous shale unit is 110 ft (34 m) thick (table 5). The contact between these two units, although not usually exposed, is sharp and often marked by a pronounced color change in weathered outcrops. The lower calcareous unit is lighter colored and contains many white-weathering, thin bentonite beds. This unit weathers bluish gray as opposed to the dark-gray to brownish weathered color of the overlying unit. Table 6 shows the location of control points used for stratigraphic cross sections shown in figs. 3 and 4 and on sheet 1 (in back pocket).

Bridge Creek Limestone Beds

The calcareous shale and limestone unit in the lower part of the Rio Salado has in the past been referred to as the Greenhorn Limestone or the Greenhorn Limestone Member of the Mancos Shale (Rankin, 1944; Lamb, 1968, 1973; McCubbin, 1969; Molenaar, 1973, 1974, 1977). Hook and Cobban (1980, 1981b) have shown that this calcareous interval is the lithologic and time equivalent of only the lower part of the Bridge Creek Limestone Member of the Greenhorn Formation in the type locality in southeast Colorado.

TABLE 5—Type section of Rio Salado Tongue of Mancos Shale, NE1/4 sec. 33, T. 3 N., R. 6 W., Puertecito 7½-min quadrangle, Socorro County, New Mexico. Measured December 1, 1977, by G. L. Massingill and S. C. Hook using Jacob's staff, Abney hand level, Brunton compass, and tape.

Unit	Lithology	Thickness ft	Thickness *m*
	Atarque Sandstone Member of the Tres Hermanos Formation:		
	(Top of exposure.)		
20	Sandstone, slightly calcareous, yellowish-orange (10YR 8/4) weathering to yellowish-orange (10YR 8/4), fine-grained; moderate sorting; moderate rounding; moderately to well-indurated; hosts large (up to 5 ft long, 1.5 ft thick), highly fossiliferous sandstone concretions at base; concretions are very fine grained, very calcareous, light-olive-gray (5Y 6/1) weathering to grayish brown (5Y 3/2).	28	*8.5*
19	Sandstone, slightly calcareous, grayish-yellow (5Y 8/4) weathering to yellowish-gray (5Y 7/2), fine-grained, poorly sorted; moderate rounding; moderately indurated, medium- to thick-bedded, burrowed.	6	*1.8*
18	Sandstone, slightly calcareous, grayish-yellow (5Y 8/4) weathering to very pale-orange (10YR 8/3), fine-grained, well-sorted; moderate rounding; well-indurated; very thick to massive bedding; forms resistant ledge; hosts large fossiliferous sandstone concretions in upper 5 ft like those in unit 20.	14.6	*4.4*
	USGS Mesozoic locality D10259 (from concretions in units 18 and 20):		
	Modiolus sp.		
	Phelopteria gastrodes (Meek)		
	Inoceramus cuvieri J. de C. Sowerby		
	Crassostrea soleniscus (Meek)		
	Pleuriocardia (Dochmocardia) n. sp.		
	Cymbophora holmesi (Meek)		
	Aphrodina sp.		
	Laternula lineata (Stanton)		
	Psilomya concentrica (Stanton)		
	Pugnellus (Gymnarus) fusiformis Meek		
	Gyrodes conradi Meek		
	G. depressus Meek		
	Pyropsis coloradoensis Stanton		
	Tectaplica? *utahensis* (Meek)		
	Carota dalli (Stanton)		
	Baculites yokoyama Tokunaga and Shimizu		
	Placenticeras cumminsi (Cragin)		
	Collignoniceras woollgari woollgari (Mantell)		
17	Sandstone, calcareous, grayish-yellow (5Y 8/4) weathering to grayish-yellow (5Y 8/4), fine-grained; moderate-sorting; poor to moderate induration; thin-bedded.	12	*3.6*
	Partial thickness of *Atarque Sandstone Member* (rounded).	61	*18.5*
	Rio Salado Tongue of Mancos Shale:		
16	Shale, noncalcareous, light-olive-gray (5Y 5/1) weathering to medium-gray (N5); soft slope-forming unit; hosts sparse fossiliferous septarian limestone concretions from 28 to 50 ft above base of unit.	110	*33.3*
	USGS Mesozoic locality D10258:		
	Placenticeras cumminsi Cragin		
	Morrowites depressus (Powell)		
	Spathites rioensis Powell		
15	Shale, calcareous, light-olive-gray (5Y 5/1) weathering to light-gray (N7); slope-forming unit.	44	*13.3*
14	Calcarenite, fossiliferous, olive-gray (5Y 5/1) weathering to dark-yellowish-brown (10YR 6/2); matrix is fine grained; well-rounded, well-sorted; contains abundant inoceramid fragments; hard, resistant bed; minor ledge (top of Bridge Creek Limestone Beds).	0.2	*.06*
13	Shale, calcareous, light-olive-gray (5Y 6/1) weathering to light-gray (N7), soft; slope-forming unit.	2.7	*.8*
12	Calcarenite, similar to unit 14.	0.3	*.09*
	USGS Mesozoic locality D10257 (from units 12 and 14):		
	Mytiloides mytiloides (Mantell)		
11	Shale, similar to unit 13, partly covered.	2	*.6*
10	Calcarenite, similar to unit 14.	0.2	*.06*
9	Shale, similar to unit 13, partly covered.	2	*.6*
8	Calcarenite, similar to unit 14.	0.1	*.03*
7	Shale, similar to unit 13, partly covered.	4	*1.2*
6	Calcarenite, similar to unit 14.	0.3	*.09*
5	Shale, partly covered, calcareous, light-olive-gray (5Y 6/1); soft slope-forming unit; *Pycnodonte newberryi* (Stanton) abundant as float in lower 10 ft.	35	*10.6*
4	Limestone, fossiliferous, shaly, nodular, yellowish-gray (5Y 8/1) weathering to light-gray (N7); slightly resistant unit (base of Bridge Creek Limestone Beds).	0.5	*.15*
	USGS Mesozoic locality D10256 (includes P. newberryi as float from units 5 and 3):		
	Hemiaster jacksoni Maury		
	Pycnodonte newberryi (Stanton)		
	Rostellites ambigua Stanton?		
	Sciponoceras gracile (Shumard)		
	Metoicoceras geslinianum (d'Orbigny)		
3	Shale, mostly covered, calcareous, medium-gray (N5) weathering to light-gray (N7); contains numerous thin (< ½ inch) bentonite beds; soft slope-forming unit; *Pycnodonte newberryi* (Stanton) as abundant float throughout unit, restricted in occurrence to upper 20 ft.	35	*10.6*
	Total thickness of *Rio Salado Tongue* (rounded).	236	*71.5*
	Twowells Tongue of Dakota Sandstone:		
2	Sandstone, noncalcareous, very pale orange (10YR 8/2) weathering to yellowish-gray (5Y 7/2), fine-grained, well-sorted, moderately rounded, very thick to thick-bedded, burrowed, moderately indurated; ledge-forming unit; contact with overlying shale is sharp, with underlying shale is gradational.	19.3	5.8
	Total thickness of *Twowells Tongue* (rounded).	19	5.8
	Mancos Shale, lower part (incomplete section):		
1	Shale, mostly covered, calcareous, light-gray.	10+	*3*
	Total thickness of lower part of *Mancos Shale* (incomplete section).	10+	*3*

TABLE 6—LOCATION OF CONTROL POINTS USED FOR STRATIGRAPHIC CROSS SECTIONS. Locations are projected where surveys are incomplete; CMM—C. M. Molenaar, JHE—J. H. Elison, RLS—R. L. Squires, BAB—B. A. Black, SCH—S. C. Hook, WAC—W. A. Cobban, and GLM—G. L. Massingill.

Control Point	Location Section		T	R	County	State	Measured by
29A	SE/4 NE/4	-13	15N	18W	McKinley	N. Mex.	CMM & RLS
29B	NW/4 NE/4	-1	15N	18W	McKinley	N. Mex.	SCH & WAC
30		-33	15N	17W	McKinley	N. Mex.	CMM
31	NW/4	-22	14N	17W	McKinley	N. Mex.	CMM
32A	NW/4	-31	13N	16W	McKinley	N. Mex.	CMM
32B	SW/4 17 to NE/4	-19	12N	16W	McKinley	N. Mex.	CMM & SCH
33		-32	11N	17W	McKinley	N. Mex.	JHE & CMM
34	SW/4 32 to NE/4	-33	10N	17W	McKinley	N. Mex.	CMM
35	NE/4	-14	8N	17W	Cibola	N. Mex.	CMM
36	SW/4 17 & SE/4	-18	4N	18W	Catron	N. Mex.	CMM
54	NW/4	-34	11N	16W	McKinley	N. Mex.	CMM
55	NW/4	-33	9N	15W	Cibola	N. Mex.	CMM
56A	SE/4 17, NW/4	-21	6N	10W	Cibola	N. Mex.	CMM
57	20, NW/4, 29-NE/4	-30	3N	8W	Socorro	N. Mex.	CMM & BAB
58A	NW/4 6, W/2	-7	2N	5W	Socorro	N. Mex.	CMM & BAB
58B		21 & 26	2N	4W	Socorro	N. Mex.	GLM
59	E/2 8 & NE/4	-17	5S	2E	Socorro	N. Mex.	BAB & CMM

The Bridge Creek Limestone Member is the uppermost of the three members of the Greenhorn Formation.

The calcareous-noncalcareous contact near the middle of the Rio Salado has been regarded as the Greenhorn–Carlile time-stratigraphic boundary (Molenaar, 1977). In west-central New Mexico, this contact is diachronous—it can lie as low as the *Mammites nodosoides* Zone or as high as the *Collignoniceras woollgari woollgari* Subzone—and it is always older than the Greenhorn–Carlile contact in the type locality in southeast Colorado, which lies in the younger *Collignoniceras woollgari regulare* Subzone. In addition, the Greenhorn–Carlile lithostratigraphic contact in the type locality is between limestone and calcareous shale, not between calcareous shale and noncalcareous shale.

Hook and Cobban (1981b) formally extended the name Bridge Creek Limestone into southern New Mexico as a member locally of the Colorado Formation and locally of the Mancos Shale. They preferred the name Bridge Creek Limestone Member to Greenhorn Limestone Member because it more accurately conveyed the stratigraphic and biostratigraphic relationships of these rocks to the Bridge Creek Member of the Greenhorn Formation of southeast Colorado. We are following Hook and Cobban's lead and extending the Bridge Creek into west-central New Mexico where it is reduced in stratigraphic rank to the Bridge Creek Limestone Beds of the Rio Salado Tongue. At Carthage, however, the limestone unit is designated as the Bridge Creek Limestone Member of the Mancos Shale (sheet 1–B, in back pocket).

The base of the Bridge Creek Limestone Beds is at the base of the lowest persistent bed of nodular to chalky limestone. This limestone is usually 2-6 inches (5-15 cm) thick and is 5-40 ft (2-12 m) above the top of the Twowells Tongue of the Dakota Sandstone. The top of the Bridge Creek Limestone Beds is placed at the uppermost persistent bed of limestone, generally a 2-4-inch (5-10-cm)-thick bed of calcarenite composed of *Inoceramus* or oyster debris. Although calcareous shale is the dominant lithology, hard resistant limestones are more conspicuous in outcrops and generally stand in topographic relief above the softer shales. Both the Bridge Creek Limestone Beds and the overlying calcareous-noncalcareous shale contact ("top of the Greenhorn Limestone") produce distinctive patterns that are easily recognized on electrical resistivity logs of wells.

At the type section of the Rio Salado Tongue, the Bridge Creek Limestone Beds are 47 ft (14 m) thick, consist of units 4 through 14 of the descriptive section (table 5), and are 35 ft (11 m) above the top of the Twowells Tongue. Throughout the area of west-central New Mexico shown on sheet 1 (in back pocket) and in figs. 3 and 4, the Bridge Creek Limestone Beds are 30-60 ft (10-20 m) thick.

The base of the Bridge Creek Limestone Beds in west-central New Mexico always lies within the late Cenomanian *Sciponoceras gracile* Zone and is regarded as an isochronous surface by Hook and Cobban (1981b). The top, however, is diachronous and can lie as low as the *Pseudaspidoceras flexuosum* Zone of latest Cenomanian or earliest Turonian age or as high as the late early Turonian *Mammites nodosoides* Zone (fig. 7).

Age

The Rio Salado Tongue of the Mancos Shale ranges in age from late Cenomanian to early middle Turonian. Fossils collected from the basal few feet of the tongue in the Acoma Basin include the oyster *Pycnodonte* aff. *P. kellumi* (Jones), which is indicative of the late Cenomanian *Metoicoceras mosbyense* Zone. The *Sciponoceras gracile* Assemblage Zone, which includes *Metoicoceras geslinianum* (d'Orbigny), *Euomphaloceras (Kanabiceras) septemseriatum* (Cragin), and *Pycnodonte newberryi* (Stanton), appears almost everywhere in the base of the Bridge Creek Limestone Beds. This assemblage zone was formally used to mark the top of the Cenomanian Stage. Concretions from the upper noncalcareous part of the Rio Salado Tongue have yielded *Collignoniceras woollgari woollgari* (Mantell) and *Morrowites depressus* (Powell), both of early middle Turonian age.

The age of the Rio Salado at any locality is, of course, dependent on the ages of both the underlying Twowells Tongue and the overlying Tres Hermanos Formation (or Atarque Sandstone). The top of the Twowells Tongue over much of west-central New Mexico is virtually synchronous (Hook and others, 1980) and lies within the upper part of the *Metoicoceras mosbyense* Zone. However, near the Arizona border at Cottonwood Canyon, 32 mi (51 km) southwest of Fence Lake, the top of the Twowells contains the ammonite *Pseudaspidoceras* and is at least three faunal zones younger than the *M. mosbyense* Zone. The Atarque Sandstone at Cottonwood Canyon contains *Morrowites subdepressus* Cobban and Hook of *Mammites nodosoides* age, thus approximately bracketing the Rio Salado Tongue between the late early Turonian *M. nodosoides* Zone and the late Cenomanian *Neocardioceras juddii* Zone.

The top of the Rio Salado Tongue becomes younger northeast of Cottonwood Canyon because of the stratigraphic rise of the Atarque Sandstone (and Member) and ranges in age from late early Turonian to early middle Turonian. At Paradise Canyon, 7 mi (11 km) southwest of Acoma Pueblo, the base of the Atarque Member lies in the early middle Turonian *Collignoniceras woollgari regulare* Subzone.

Discontinuity surfaces and disconformities

Hook and Cobban (1981b) documented paleontologically the existence of three discontinuity surfaces within rocks of the Bridge Creek Limestone Member of the Colorado Shale in the Cooke's Range. We have not yet been able to demonstrate them within the Bridge Creek Limestone Beds of the Rio Salado Tongue. However, we have collected oyster-and bryozoan-encrusted internal molds of *Morrowites depressus* (Powell) of Cobban and Hook (1983) from the upper part of the Rio Salado Tongue at Puertecito, D Cross Mountain, and Fence Lake. Some of these molds have been mineralized by iron; most have been broken or show evidence of erosion. Those from Fence Lake have a composition which differs from that of the surrounding concretion. In addition, at each locality the molds are concentrated into a single bed. Hook and Cobban (1981b) suggested that these molds of *Morrowites depressus* (Powell) may have been concentrated on a widespread, submarine erosion surface that extended at least from Capitan on the east to Fence Lake on the west.

Mappability

The Rio Salado Tongue of the Mancos Shale is present over much of west-central New Mexico wherever both the overlying Tres Hermanos Formation (or Atarque Sandstone) and the underlying Twowells Tongue of the Dakota Sandstone are present. The Rio Salado Tongue has been mapped in most of the areas that the Tres Hermanos Formation has been mapped (see page 23, this report). S. L. Moore (personal communication, 1981) has mapped it in the northern Acoma Basin, Osburn (1982, 1983) in the southern Acoma Basin, and McLellan and others (personal communication, 1981) and Anderson (1981, 1982) in the southern Zuni Basin.

East of Puertecito, the Twowells Tongue of the Dakota Sandstone pinches out into the Mancos Shale. Although both time and lithologic equivalents of the Rio Salado Tongue can be recognized from Riley to Carthage to Truth or Consequences, the Rio Salado Tongue cannot be differentiated out of this larger body of shale that extends from the top of the main body of the Dakota Sandstone to the base of the Tres Hermanos Formation. In those areas, strata equivalent to the Rio Salado are included within the undifferentiated Mancos Shale. However, individual limestones within the Bridge Creek Limestone Beds of the Rio Salado Tongue can be traced in continuous outcrop from Puertecito to Riley and correlated with equivalent beds at Carthage and Truth or Consequences.

Characteristic fauna

The Rio Salado Tongue of the Mancos Shale is almost exactly the same age as the entire Bridge Creek Limestone Member at the type locality of the Greenhorn Formation near Pueblo, Colorado, and is characterized by many of the same species of fossils. The easily recognizable oyster *Pycnodonte newberryi* (Stanton) occurs in great abundance in shales and limestones near the base of the tongue along with the ammonites *Worthoceras gibbosum* Moreman, *Sciponoceras gracile* (Shumard), and *Euomphaloceras (Kanabiceras) septemseriatum* (Cragin). Illustrations and descriptions of these species can be found in Cobban and Scott (1972) and Hook and Cobban (1977).

The middle part of the Rio Salado Tongue is characterized by the inoceramid *Mytiloides mytiloides* (Mantell), which occurs in great abundance, although generally fragmented, in the calcarenite beds at the top of the Bridge Creek Limestone Beds. Illustrations of this species can be found in Kauffman (1977, pl. 6, figs. 6 and 7).

Ammonites are the dominant group of mollusks that occur in concretions in the upper part of the Rio Salado Tongue. Cobban and Hook (1979a) listed 10 species of ammonites from this interval. Since then, several more have been identified, including a new genus that occurs abundantly in the Fence Lake area; these will be described in another report. This fauna includes *Mammites nodosoides* (Schlüter), *Morrowites depressus* (Powell), *Spathites rioensis* Powell, and *Collignoniceras woollgari woollgari* (Mantell). Illustrations and descriptions of all these species can be found in Cobban and Hook (1979a, 1983).

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PRINCIPAL REFERENCE SECTION AND CORRELATION OF GALLUP SANDSTONE, NORTHWESTERN NEW MEXICO

by C. M. Molenaar, *U.S. Geological Survey, Denver, Colorado*

Abstract

Because a type section has never been designated for the Gallup Sandstone, a principal reference section is herein designated 2 mi (3 km) east of Gallup, New Mexico. At the principal reference section, the Gallup Sandstone is 332 ft (101 m) thick and consists of offshore marine sandstones and marine shale tongues in the lower part that grade up to shoreface or coastal shoreline sandstone in the middle part and to nonmarine carbonaceous shale and fluvial sandstones in the upper part. The upper medium- to coarse-grained fluvial sandstone unit is called the Torrivio Member. The Gallup overlies and intertongues with the underlying Mancos Shale and is overlain, at least locally unconformably, by the upper Mancos Shale in areas of its northeastern extent. To the southwest of the San Juan Basin, the Gallup is overlain by the nonmarine Crevasse Canyon Formation. Strata below the Pescado or D-Cross Tongues of the Mancos in the Zuni and Acoma Basins and formerly referred to as lower part of Gallup by Pike (1947) and Atarque Member of Gallup by Molenaar (1973, 1974) are herein excluded from the Gallup and are now assigned to the newly defined Tres Hermanos Formation. Also recommended is that the name "Gallego Sandstone" of the southern Acoma Basin be abandoned, inasmuch as it is equivalent to the Gallup Sandstone. As defined, the Gallup Sandstone can be recognized over a wide area of northwest and south-central New Mexico.

Introduction

The Gallup Sandstone (Upper Cretaceous) of northwest New Mexico is a well-known regressive marine and nonmarine sequence that was deposited during a regional regression in late Turonian to early Coniacian time. The Gallup overlies and intertongues with the underlying Mancos Shale and is overlain, at least locally unconformably, by the lower part of the upper Mancos Shale in areas of its northeast extent. Southwest of the San Juan Basin, the Gallup is overlain by the nonmarine Crevasse Canyon Formation.

The name "Gallup Sandstone Member of the Mesaverde Formation" was first applied by Sears (1925, p. 17) to a mappable sequence of rocks near Gallup, New Mexico. Later, the Gallup nomenclature was extended throughout northwest and west-central New Mexico, and in 1956, Beaumont, Dane, and Sears raised the Gallup Sandstone from a member to a formation and the Mesaverde from a formation to a group.

The inclusion of the Gallup Sandstone, as well as the Crevasse Canyon Formation and older units in west-central New Mexico, in the Mesaverde Group is extending the term Mesaverde to much older rocks in areas far beyond the area where the Mesaverde was originally defined. At this time, I am excluding the Gallup, Crevasse Canyon, and older rocks from the Mesaverde Group. This problem, however, warrants further discussion with other workers in the area.

Because Sears did not designate a type section of the Gallup Sandstone (a not uncommon practice in those days) and because the Gallup nomenclature has been misapplied and miscorrelated in some areas, the purpose of this report is twofold—first, to designate and describe a principal reference section for the Gallup, and second, to show the correlation of the Gallup in northwest New Mexico. The reference section is in the SE 1/4 NE 1/4 sec. 13, T. 15 N., R. 18 W. on the north side of Puerco Gap 2 mi (3 km) east of the city of Gallup (figs. 9 and 10). The Santa Fe Railroad line, US-66, and the Puerco River pass through this gap just south of the reference section. The new highway cut of 1-40 is approximately 600-900 ft (180-275 m) north of the reference section. Six stratigraphic cross sections are included to show the internal variations and correlations of the Gallup Sandstone throughout the area (fig. 10).

This report is an interim progress report; a more extensive stratigraphic and biostratigraphic study of mid-Cretaceous strata throughout western New Mexico is planned.

Much of the field work on which this report is based was done while the writer was working for Shell Oil Company. The writer gratefully acknowledges Shell for permission to publish this material. J. E. Fassett and A. R. Kirk of the U.S. Geological Survey critically reviewed this report.

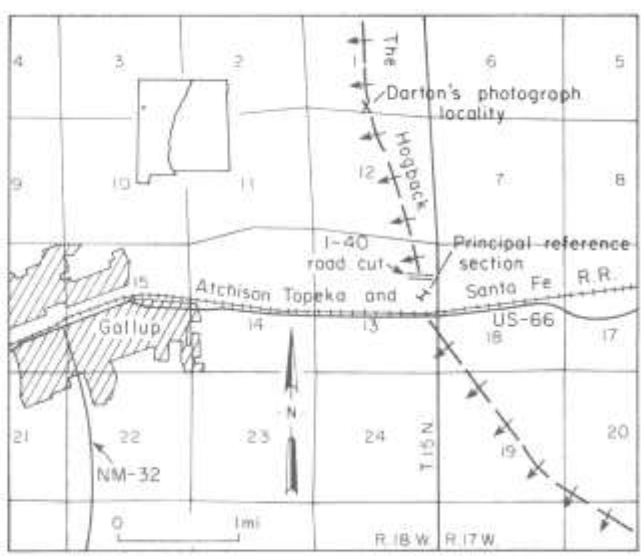

FIGURE 9—LOCATION OF TYPE AREA AND PRINCIPAL REFERENCE SECTION OF GALLUP SANDSTONE; base map is from part of Gallup East 7 1/2-min quadrangle. See fig. 10 for small-scale index map.

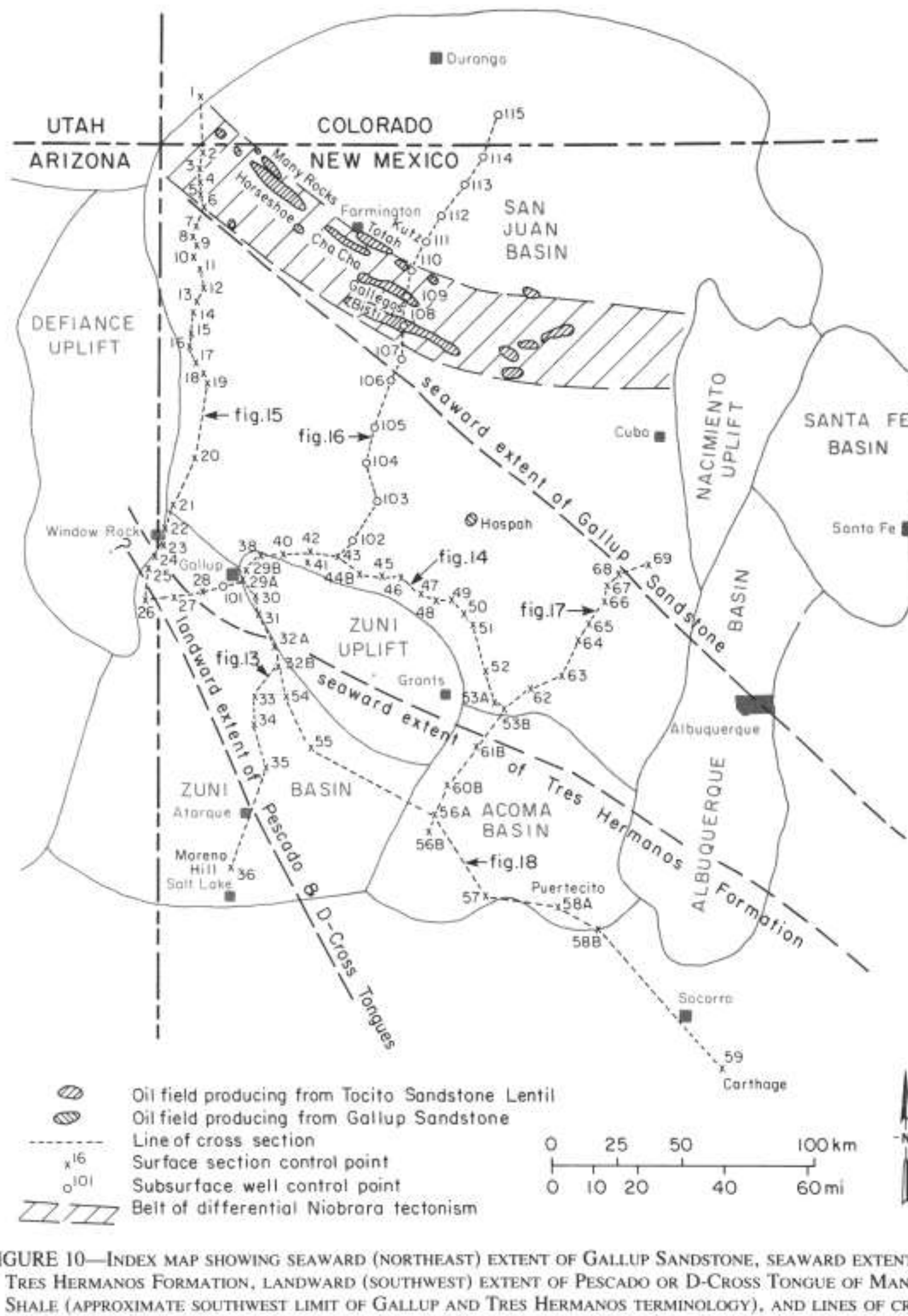

FIGURE 10—Index map showing seaward (northeast) extent of Gallup Sandstone, seaward extent of Tres Hermanos Formation, landward (southwest) extent of Pescado or D-Cross Tongue of Mancos Shale (approximate southwest limit of Gallup and Tres Hermanos terminology), and lines of cross sections of this report and related report in this circular (modified from Molenaar, 1973). Principal reference section of Gallup Sandstone is control point 29A; see table 7 for locations of control points.

TABLE 7—LOCATION OF CONTROL POINTS USED IN STUDY. Locations are projected where surveys are incomplete; CMM—C. M. Molenaar, JCL—J. C. Lawther, JHE—J. H. Elison, WDB—W. D. Bacheller, RLS—R. L. Squires, TDF—T. D. Fouch, RWF—R. W. Fields, BAB—B. A. Black, TRM—T. R. Magorian, RK—R. Kadwell, SCH—S. C. Hook, WAC—W. A. Cobban, and GLM—G. L. Massingill.

Surface control

Control Point	Section	Location T	Location R	County	State	Measured by
1	NW¼ 25 & NE¼ 26	34N	19W	Montezuma	CO	CMM, JCL
2	S½ S½ 17	32N	19W	San Juan	NM	CMM
3	C 6	31N	19W	San Juan	NM	JHE, WDB
4	NE¼ 30	31N	19W	San Juan	NM	JHE, WDB
5	N½ 5	30N	19W	San Juan	NM	JHE, WDB
6	N½ 20	30N	19W	San Juan	NM	CMM
7	SE¼ 12 &	29N	20W	San Juan	NM	JHE, WDB, CMM
	SW¼ 7	29N	19W			
8	S½ 25 & SE¼ 26	29N	20W	San Juan	NM	JHE, WDB, CMM
9	SW¼ 7 &	28N	19W	San Juan	NM	JHE, WDB
	SE¼ 12	28N	20W			
10	SE¼ 25 &	28N	20W	San Juan	NM	JHE, WDB
	SW¼ 30	28N	19W			
11	C 17	27N	19W	San Juan	NM	CMM, JCL
12	33	27N	19W	San Juan	NM	CMM, JCL
13	SE¼ SE¼ 18	26N	19W	San Juan	NM	CMM, RLS
14	SW¼ SW¼ 31	26N	19W	San Juan	NM	CMM, RLS
15	NW¼ NW¼ 30	25N	19W	San Juan	NM	RLS, JCL
16	SW¼ SW¼ 12	24N	20W	San Juan	NM	CMM, RLS
17	SE¼ 31	24N	19W	San Juan	NM	CMM, RLS
18	NW¼ 16	23N	19W	San Juan	NM	CMM, JCL
19	SW¼ 27	23N	19W	San Juan	NM	CMM, JCL
20	W½ 19	20N	19W	McKinley	NM	CMM, JCL
21	NE¼ 17	18N	20W	McKinley	NM	CMM
22	NE¼ 12	17N	21W	McKinley	NM	CMM
23	NW¼ 36	17N	21W	McKinley	NM	CMM, JCL
24	SE¼ 30	26N	31E	Apache	AZ	CMM
25	SE¼ 12	25N	30E	Apache	AZ	CMM
26	SE¼ 24	24N	30E	Apache	AZ	CMM
27	SE¼ 31	15N	20W	McKinley	NM	CMM, TDF
28	NE¼ 29	15N	19W	McKinley	NM	CMM
29A	SE¼ NE¼ 13	15N	18W	McKinley	NM	CMM, RLS
29B	NW¼ NE¼ 1	15N	18W	McKinley	NM	SCH, WAC
30	33	15N	17W	McKinley	NM	CMM
31	NW¼ 22	14N	17W	McKinley	NM	CMM
32A	NW¼ 31	13N	16W	McKinley	NM	CMM
32B	SW¼ 17 to NE¼ 19	12N	16W	McKinley	NM	CMM, SCH
33	32	11N	17W	McKinley	NM	JHE, CMM
34	SW¼ 32 to NE¼ 33	10N	17W	McKinley	NM	CMM
35	NE¼ 14	8N	17W	Cibola	NM	CMM
36	SW¼ 17 & SE¼ 18	4N	18W	Catron	NM	CMM
37	E½ SW¼ 34	14N	20W	McKinley	NM	CMM
38	NW¼ 10 & NW¼ 15	16N	17W	McKinley	NM	CMM
39	Not used					
40	SE¼ 10 & NW¼ 11	16N	16W	McKinley	NM	CMM, RLS
41	NE¼ 21 & NW¼ 22	16N	15W	McKinley	NM	CMM
42	NE¼ 10 to C 3	16N	15W	McKinley	NM	CMM
43	15	16N	14W	McKinley	NM	RWF
44B	SW¼ 33 & SE¼ 32	16N	13W	McKinley	NM	CMM, SCH
45	SW¼ 9	15N	12W	McKinley	NM	CMM, RLS
46	7	15N	11W	McKinley	NM	RWF
47	36	15N	11W	McKinley	NM	RWF
48	4	14N	10W	McKinley	NM	RWF
49	1	14N	10W	McKinley	NM	RWF
50	22	14N	9W	McKinley	NM	RWF
51	6	13N	8W	McKinley	NM	RWF
52	E½ SW¼ 28	12N	8W	Cibola	NM	CMM, RLS
53A	N½ NE¼ 2	10N	8W	Cibola	NM	CMM, RLS
53B	SW¼ SW¼ 4	10N	7W	Cibola	NM	CMM, SCH
54	NW¼ 34	11N	16W	McKinley	NM	CMM
55	NW¼ 33	9N	15W	Cibola	NM	CMM
56A	SE¼ 17 NW¼ 21	6N	10W	Cibola	NM	CMM
56B	NW¼ NE¼ 1	5N	11W	Cibola	NM	CMM, SCH
57	20 & NW¼ 29 & NE¼ 30	3N	8W	Socorro	NM	CMM, BAB
58A	NW¼ 6 & W½ 7	2N	5W	Socorro	NM	CMM, BAB
58B	21 & 26	2N	4W	Socorro	NM	GLM
59	E½ 8 & NE¼ 17	5S	2E	Socorro	NM	BAB, CMM
60B	SW¼ 11 & NW¼ 14	7N	10W	Cibola	NM	CMM, SCH
61B	SW¼ 29 & NE¼ 31	9N	8W	Cibola	NM	CMM, SCH
62	E½ 19	11N	6W	Cibola	NM	CMM, RLS
63	E½ 4	11N	5W	Cibola	NM	JHE, RK
64	30	13N	4W	Sandoval	NM	JHE, RK
65	SE¼ 4	13N	4W	Sandoval	NM	CMM, TDF
66	SW¼ SW¼ 7	14N	3W	Sandoval	NM	CMM, RLS
67	NE¼ SW¼ 27	15N	3W	Sandoval	NM	JHE, RK
68	E½ 10	15N	3W	Sandoval	NM	JHE, RK
69	NW¼ NW¼ 36	16N	2W	Sandoval	NM	JHE, RK

TABLE 7 (con't)

Subsurface control

Control Point	Well		Section	T	R	County	State
101	H. P. Doty Water Well	No. 11	20	15N	18W	McKinley	NM
102	U. F. Maddox	No. 1	28	17N	13W	McKinley	NM
103	Jones & Peachee	No. 1	8	18N	12W	McKinley	NM
104	Sinclair Oil & Gas	No. 1	26	20N	13W	McKinley	NM
105	Sinclair Oil & Gas	No. 1	18	21N	12W	San Juan	NM
106	Humble Oil & Ref.	No. 2	23	23N	12W	San Juan	NM
107	Magnolia Pet.	No. 1	29	24N	11W	San Juan	NM
108	Shell Oil	No. 113–17	17	25N	11W	San Juan	NM
109	Pan American Pet.	No. 1	9	26N	11W	San Juan	NM
110	Sinclair Oil & Gas	No. 7	10	27N	11W	San Juan	NM
111	So. Union Prod.	No. 1B	31	29N	10W	San Juan	NM
112	So. Union Prod.	No. 3	34	30N	10W	San Juan	NM
113	Tenneco Oil	No. 1	27	31N	9W	San Juan	NM
114	Aztec Oil & Gas	No. 1	21	32N	8W	San Juan	NM
115	El Paso Nat. Gas	No. 18	16	33N	7W	La Plata	CO

Principal reference section and definition of Gallup Sandstone

Sears (1925, p. 17) described the Gallup Sandstone as consisting of three massive sandstone beds interbedded with shale and coal and ranging from 180 to 250 ft (55 to 76 m) in thickness. In addition, he stated that the Gallup was well exposed along The Hogback east of Gallup. On a photograph taken by N. H. Darton in 1901, Sears (1925, pl. V) shows the Gallup Sandstone, with contacts annotated, as it is exposed at a gap in The Hogback 2 1/2 mi (4 km) northeast of Gallup (C S1/2 S1/2 sec. 1, T. 15 N., R. 18 W.). This photograph was used in subsequent reports to show the "type" area of the Gallup Sandstone (Sears and others, 1941, pl. 27—B; O'Sullivan and others, 1972, fig. 12).

The principal reference section of this report is 11/2 mi (2 1/2 km) south of Darton's photograph locality (fig. 9). The exposures are considered to be better, and more of the lower part of the section is exposed at the reference locality. This section was measured and described by the writer and R. L. Squires in 1968, and was included in a paper by Molenaar (1973, p. 101). Table 8 is a detailed lithologic description of the principal reference section. In addition, fig. 11 is a photograph and fig. 12 is a graphic representation of the section. Also shown are the relationships of the units Sears described. In his original description, Sears referred to three massive prominent sandstone beds that crop out on The Hogback as shown in Darton's photograph. The lower sandstone bed is pink and, at the reference locality, is split by a 10-ft-thick silty shale tongue into two sandstone units. This shale tongue is not present in the area of Darton's photograph, possibly because of tectonic elimination or faulting along the steeply dipping monocline. The shale tongue is present again a short distance farther north. The medial sandstone bed referred to by Sears is buff or light gray and is the uppermost marine sandstone in the section. The upper sandstone bed is red or pink and is a coarse-grained nonmarine fluvial unit. This unit was named the Torrivio Sandstone Member of the Gallup by Molenaar (1973, p. 98; to be discussed).

An underlying sandstone bed was not included in the Gallup by Sears, probably because it is so poorly exposed in the immediate area and thus was difficult to map. However, this sandstone bed is a prominent bed to the south and east of the Gallup area and is herein included in the Gallup. This bed already has been included in the Gallup in published U.S. Geological Survey quadrangle maps along the southern flank of the San Juan Basin where it has been referred to as a lower sandstone or tongue of Gallup (Kirk and others, 1978, p.32). In areas to the south and southeast of the type area, it is the first major sandstone unit above the widespread Pescado Tongue or D-Cross Tongue of the Mancos Shale of the Zuni and Acoma Basins, respectively, and is the basal sandstone of a major regressive cycle of deposition. Thus, it defines the base of the Gallup Sandstone in areas south and southeast of the San Juan Basin. From the outcrop belt east of Gallup to the northeastward pinchout or termination of the Gallup Sandstone in the San Juan Basin, the base of the Gallup is placed at the first prominent sandstone unit above the Juana Lopez Member of the Mancos Shale. The Juana Lopez is a series of distinctive calcarenite beds of early late Turonian age (figs. 13-17).

The top of the Gallup is retained as originally defined by Sears, which in the Gallup area is a prominent pink fluvial sandstone (Torrivio Member). In areas where this fluvial sandstone is not present, such as in the southeast San Juan Basin, Acoma Basin, and the Carthage area, the top of the Gallup is placed at the top of the highest regressive shoreface sandstone, which is usually a prominent, resistant, cliff-forming unit (figs. 14, 17, and 18).

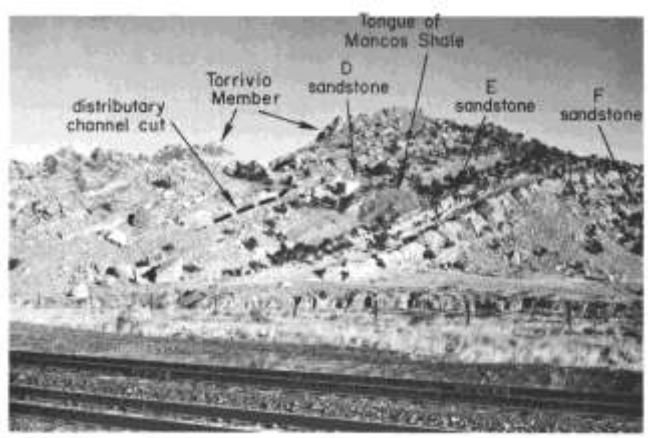

FIGURE 11—PHOTOGRAPH OF GALLUP SANDSTONE AT PRINCIPAL REFERENCE SECTION; view is to northwest.

TABLE 8—PRINCIPAL REFERENCE SECTION OF GALLUP SANDSTONE AND TYPE SECTION OF TORRIVIO MEMBER, SE1/4 NE1/4 sec. 13, T. 15 N., R. 18 W., Gallup East 71/2-min quadrangle, McKinley County, New Mexico. Measured by C. M. Molenaar and R. L. Squires, using Jacob's staff and Brunton compass; see fig. 12 for graphic representation.

Unit	Lithology	Thickness ft	Thickness *m*
	Dilco Coal Member of Crevasse Canyon Formation		
	(Covered in immediate area, but is well exposed ¾ mi to north. Not described in detail)		
	Mudstone, carbonaceous and coaly with thin 1–3-ft-thick beds of very fine grained sandstone. Common thin coal beds in lower half.	150+	*48+*
	Top of Gallup Sandstone		
	Torrivio Member		
19	Sandstone, red-pink, upper fine-grained, slightly coarser near base, well-sorted, massive, quartzose and feldspathic.	15	*4.6*
18	Covered interval—probably shale.	3	*0.9*
17	Sandstone, red-pink, upper fine- to coarse-grained with granules in lower 8 ft, upper fine-grained in upper part; medium and coarser grains are very angular; quartzose and feldspathic, massive to medium-scale crossbedded.	13	*4.0*
16	Shale (mostly covered), dark-gray, fissile.	8	*2.4*
15	Sandstone, red-pink, upper fine-grained, well-sorted, quartzose and feldspathic, medium-scale crossbedded and some channel-bank lateral-accretion bedding.	11	*3.4*
14	Shale, dark-gray, fissile.	3	*0.9*
13	Sandstone, buff, medium-grained; abundant clay pebbles; well-sorted, quartzose and feldspathic; irregular bedding.	2	*0.6*
	Total *Torrivio Member*	55	*16.8*
	Undifferentiated *Gallup Sandstone*		
12	Shale 90% and sandstone 10%		
	Shale, dark-gray, slightly fissile, mostly noncarbonaceous to slightly carbonaceous with minor carbonaceous shale. Sandstone, buff, lower very fine to upper very fine grained; in thin ripple-bedded units as much as 1 ft thick. (This is a tongue of Crevasse Canyon Formation.)	28	*8.5*
11	Sandstone, buff, lower fine-grained, very well sorted; abundant burrows including ophiomorpha; flat-bedded. This unit terminates abruptly to south by pinchout or truncation and continues to north at least several hundred ft. Interpreted to be back-barrier washover sandstone.	5	*1.5*
10	Shale, dark-gray, fissile, very carbonaceous and coaly near base and top. Back-barrier paludal to lagoonal shale unit. (This is a tongue of Crevasse Canyon Formation.)	10	*3.0*
9	Sandstone (D Ss) buff, upper very fine grained at base, lower fine-grained at top with upper fine-grained at 30–35 ft, flat-bedded to massive with some low-angle crossbeds at 30–40 ft, well-sorted; some interstitial clay; slightly feldspathic; minor muscovite; common burrows in lower 30 ft; minor burrows above. Top of unit is carbonaceous and contains root tubes. This sandstone is a regressive shoreface to foreshore sequence. The unit is cut by a distributary channel immediately to the south (adjacent to small gap in upper part of hogback; fig. 11). Channel is filled in lower part with 15 ft of red, lower medium- to upper fine-grained, feldspathic, moderately sorted sandstone with abundant shale clasts at base (active channel fill). Remainder of channel is interbedded sandstone (65%) and shale (35%; inactive fill). Sandstone is lower fine-grained and thin-bedded; shale is gray and fissile.	50	*15.2*
8	Sandstone, shale, and siltstone, interbedded and grading from shale below to sandstone above, burrowed.	25	*7.6*
7	Shale and siltstone (or mudstone), dark-gray, thin-bedded, marine, common calcareous concretions in lower part, *Inoceramus* sp. (This is an unnamed tongue of Mancos Shale.)	25	*7.6*
6	Sandstone and siltstone, basal 3 inches is medium- to coarse-grained with granules; remainder is lower fine- to very fine grained sandstone and siltstone; burrowed and bioturbated. This is a transgressive unit.	5	*1.5*
5	Sandstone (E Ss), buff to pink, lower very fine grained at base grading up to lower fine-grained at top, flat-bedded with some low-angle crossbeds a few feet below top; white interstitial clay (altered feldspar?); bioturbated in lower part; abundant burrows above; 2-ft very calcareous bed 6 ft from top. This is an offshore marine sandstone.	24	*7.3*
4	Sandstone, siltstone, and shale, interbedded and grading up to sandstone above, burrowed, concretions at base.	10	*3.0*
3	Sandstone, pink, lower very fine grained at base grading up to upper lower fine-grained at top, massive, well-sorted; some white interstitial clay (altered feldspar?); burrows in lower part and abundant burrows in top foot including ophiomorpha; very calcareous at top; interference ripple marks on top surface; flat-bedded in lower 20 ft, flat-bedded with some crossbeds in upper 17 ft. This is an offshore marine sandstone that pinches out 3 mi to the southeast and 4 mi to the north.	37	*11.3*
2	Siltstone, shale, and sandstone, mostly covered, interbedded. This is a transgressive marine shale tongue of the Mancos that grades up to overlying sandstone.	18	*5.5*
1	Sandstone (F Ss), yellowish-buff, lower very fine grained grading up to upper very fine grained at top, massive, well-sorted, highly burrowed including ophiomorpha, bioturbated. This is an offshore marine sandstone.	40	*12.2*
	Total *Gallup Sandstone* (including tongues of Mancos Shale and Crevasse Canyon Formation).	332	*101*
	Part of *Mancos Shale*		
	Siltstone, coarse, buff-weathering, bioturbated. This is transitional with covered Mancos Shale below.	10	*3*

As thus defined, the Gallup Sandstone comprises a sequence of strata that can be recognized and mapped over a wide area (fig. 10). Where the map scale permits, the marine shale tongues that separate the sandstone beds in the lower part of the Gallup can be mapped as tongues of Mancos Shale. The nonmarine shale tongue in the upper part of the Gallup can be mapped as a tongue of the Crevasse Canyon Formation.

Torrivio Member of Gallup Sandstone

The Torrivio Sandstone Member of the Gallup Sandstone was proposed by Molenaar (1973) for the upper pink fluvial sandstone unit of the Gallup. Herein recommended is that it be known as the Torrivio Member (without the word "Sandstone"). It was named for exposures of the unit on and around Torrivio Mesa approximately 8 mi (13 km) west-southwest of Gallup. The type section is designated at the principal reference section of the Gallup, where its relationships with the remainder of the Gallup and the overlying Dilco Coal Member of the Crevasse Canyon Formation are clearly shown either in the section or in the immediate area. The Torrivio is a medium- to coarse-grained, crossbedded fluvial sandstone unit that can be distinguished from other sandstone units above and below by its coarse-grained texture. It consists of as many as three sandstone beds separated by interchannel carbonaceous shale, siltstone, fine-grained sandstone, and minor coal beds. In the Gallup area and south, the Torrivio is mostly red or pink, but along the south flank of the San Juan Basin and north of Todilto Park along the west side, it is generally buff or light gray. The total unit ranges in thickness from more than 100 ft (30 m) to a pinchout edge 48 mi (77 km) east of Gallup (fig. 14). It pinches out between nonmarine beds of the Dilco Coal Member of the Crevasse Canyon Formation and nonmarine beds of the Gallup Sandstone. Where that occurs, the top of the Gallup arbitrarily drops down to the top marine sandstone, and the nonmarine beds are mapped as Dilco (fig. 14).

Kirk and others (1978), who have mapped many of the 1:24,000-scale quadrangle maps along the southern flank of the San Juan Basin, suggested alternate ways in which the Gallup could be redefined. They thought it would be more reasonable to place the top of the Gallup at the top of the highest marine sandstone and to include the Torrivio and associated nonmarine rocks in the overlying Crevasse Canyon Formation. Genetically, this assignment makes a more meaningful contact. Also, the top marine sandstone is a more consistent unit to map in the subsurface (fig. 16). However, the top of the Torrivio Member fits the criterion of mappability better in much of the outcrop area, especially in areas south and west of Gallup, where stratigraphic details of the marine section are more complex (figs. 14, 15, and 18). The top marine sandstone in some of those areas is difficult to differentiate without close inspection. Also, the top of the Torrivio has been used extensively in the past for the top of the Gallup. Both sides of the argument as to whether or not the Gallup Sandstone should be redefined have merits. To resolve these differences, a meeting attended by numerous interested participants was held in Denver, Colorado, on February 2, 1978, under the auspices of the Geologic Names Committee (GNC) of the U.S. Geological Survey. As a result of this meeting, the GNC recommended that the upper coarse-grained pink sandstone described by Sears (1925), the Torrivio Member of Molenaar (1973), be retained as the top of the Gallup Sandstone.

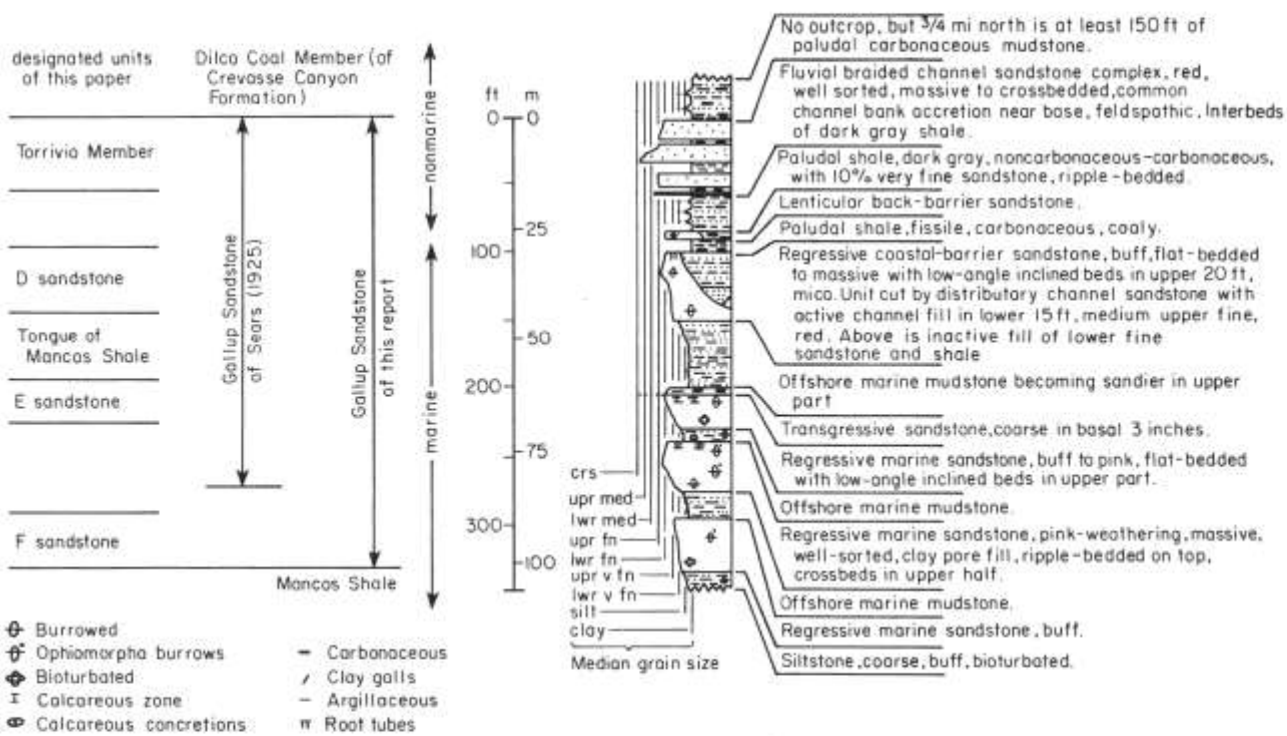

FIGURE 12—Graphic representation of principal reference section of Gallup Sandstone and type section of Torrivio Member (control point 29A, SE1/4 NE1/4 sec. 13, T. 15 N., R. 18 W., McKinley County, New Mexico; modified from Molenaar, 1973).

Correlations and relationships of underlying and overlying formations

Six stratigraphic cross sections show the internal correlations and facies of the Gallup Sandstone and adjacent strata in the San Juan, Acoma, and Zuni Basins (figs. 13-18). These sections are revisions or modifications from Molenaar (1973, 1974). Additional field work resulted in the correction of two previous miscorrelations; one on the section from Moreno Hill to the Gallup area (between control points 31 and 32A in fig. 13) and the other on the section from the western Acoma Basin to the southeastern San Juan Basin (between control points 53B and 61B in fig. 17). Inasmuch as these cross sections include new or revised stratigraphic terminology described in accompanying reports in this volume, brief definitions of these units follow.

To the south and southeast of Gallup, marine and nonmarine strata below the Pescado and D-Cross Tongues of the Mancos that were formerly referred to as lower Gallup or Atarque Member of the Gallup by Molenaar (1973, 1974) and lower part of Gallup or Atarque Member of the Mesaverde Formation (subsequently raised to group status) by Pike (1947, p. 35) are now included in the Tres Hermanos Formation. In addition, the Tres Hermanos has been subdivided into three members which, in ascending order, are Atarque Sandstone Member, Carthage Member, and Fite Ranch Sandstone Member, as shown on the cross sections (figs. 13, 17, and 18). See Hook, Molenaar, and Cobban (this volume) for details on the Tres Hermanos Formation.

In areas of west-central and southwest New Mexico where the Pescado and D-Cross Tongues have pinched out, the

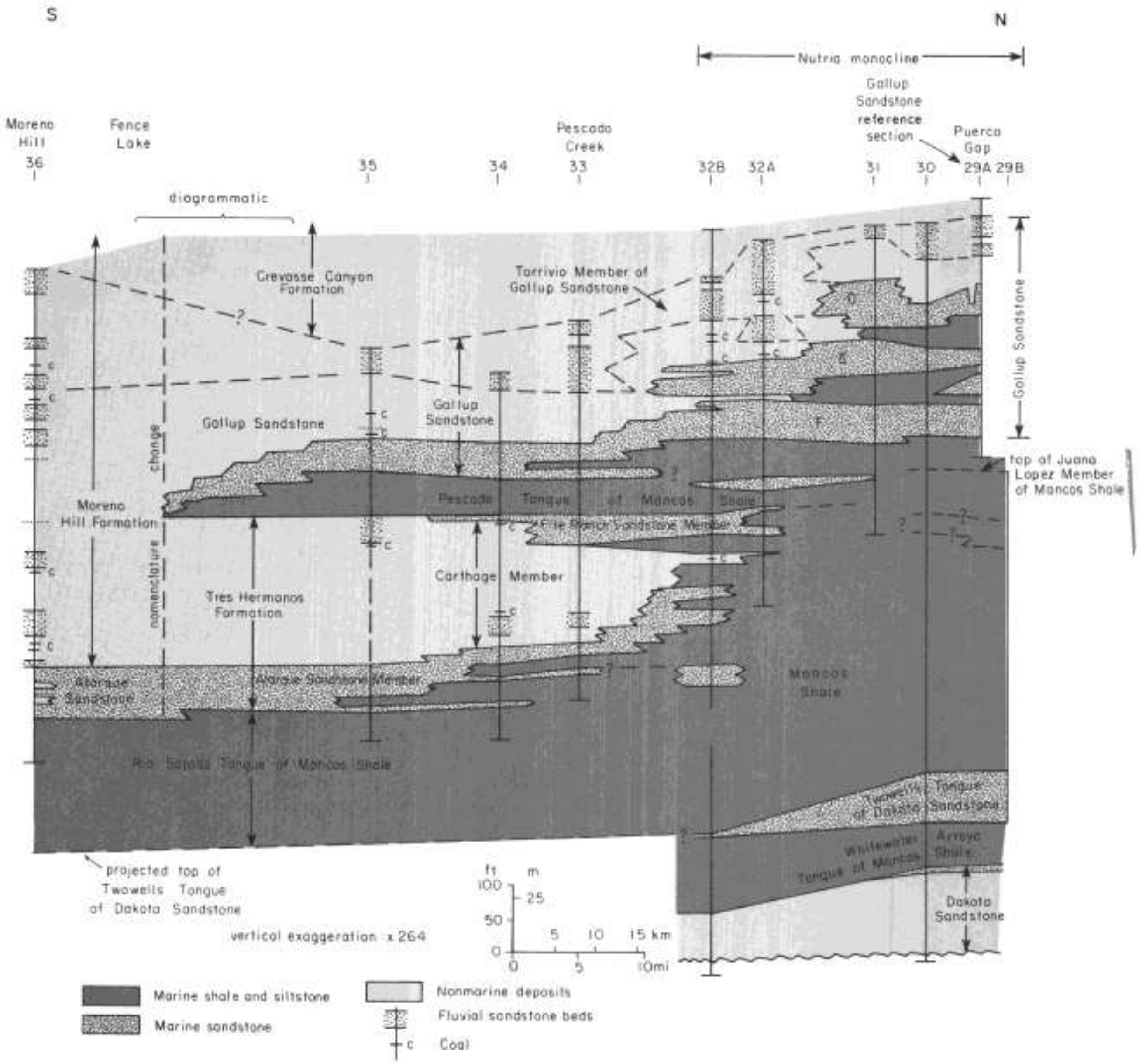

FIGURE 13—STRATIGRAPHIC CROSS SECTION FROM MORENO HILL TO GALLUP AREA (PRINCIPAL REFERENCE SECTION; REVISED FROM MOLENAAR, 1973); see fig. 10 and table 7 for location of section and/or control points.

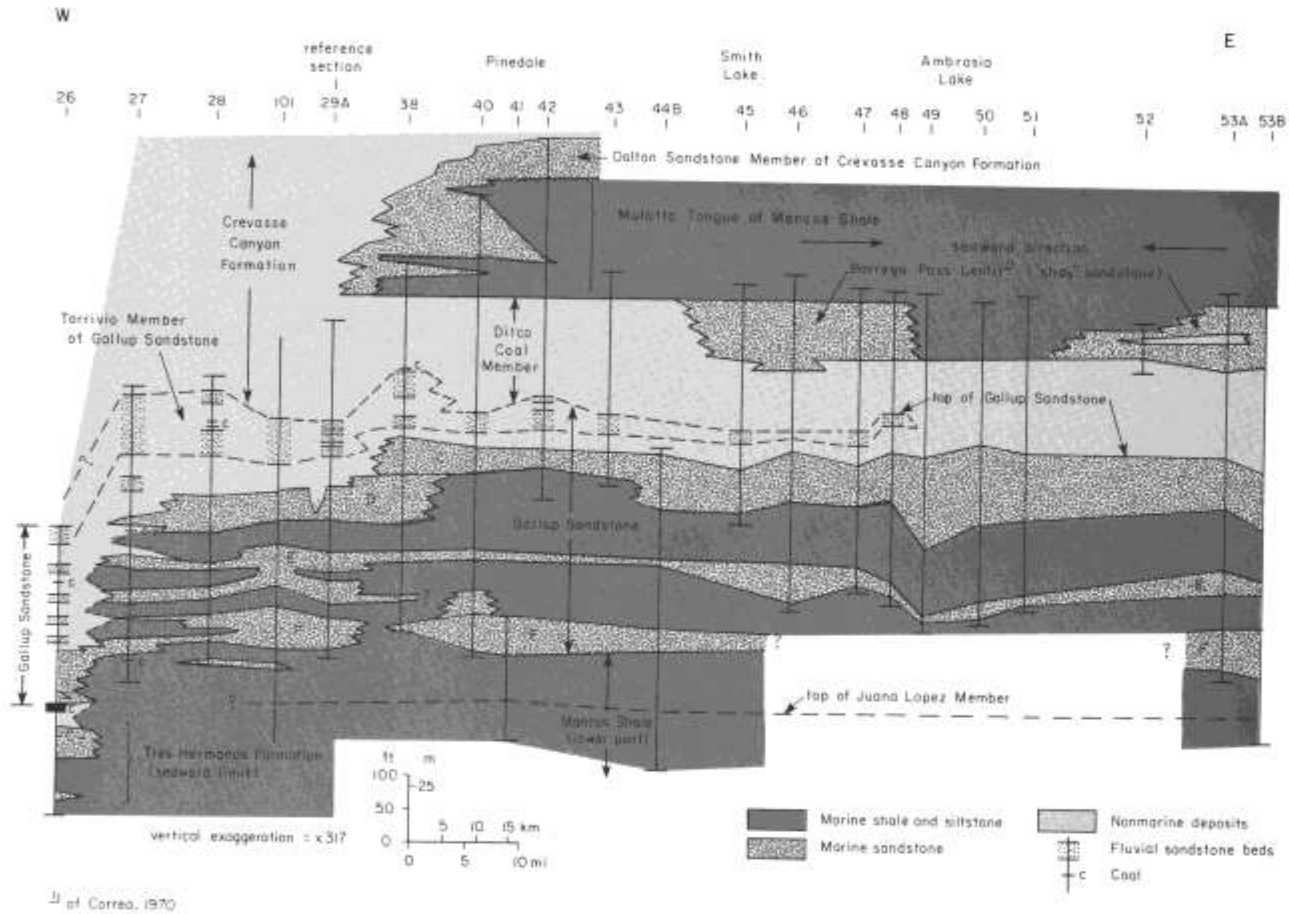

FIGURE 14—STRATIGRAPHIC CROSS SECTION ALONG SOUTH SIDE OF SAN JUAN BASIN (MODIFIED FROM MOLENAAR, 1973); see fig. 10 and table 7 for location of section and/or control points.

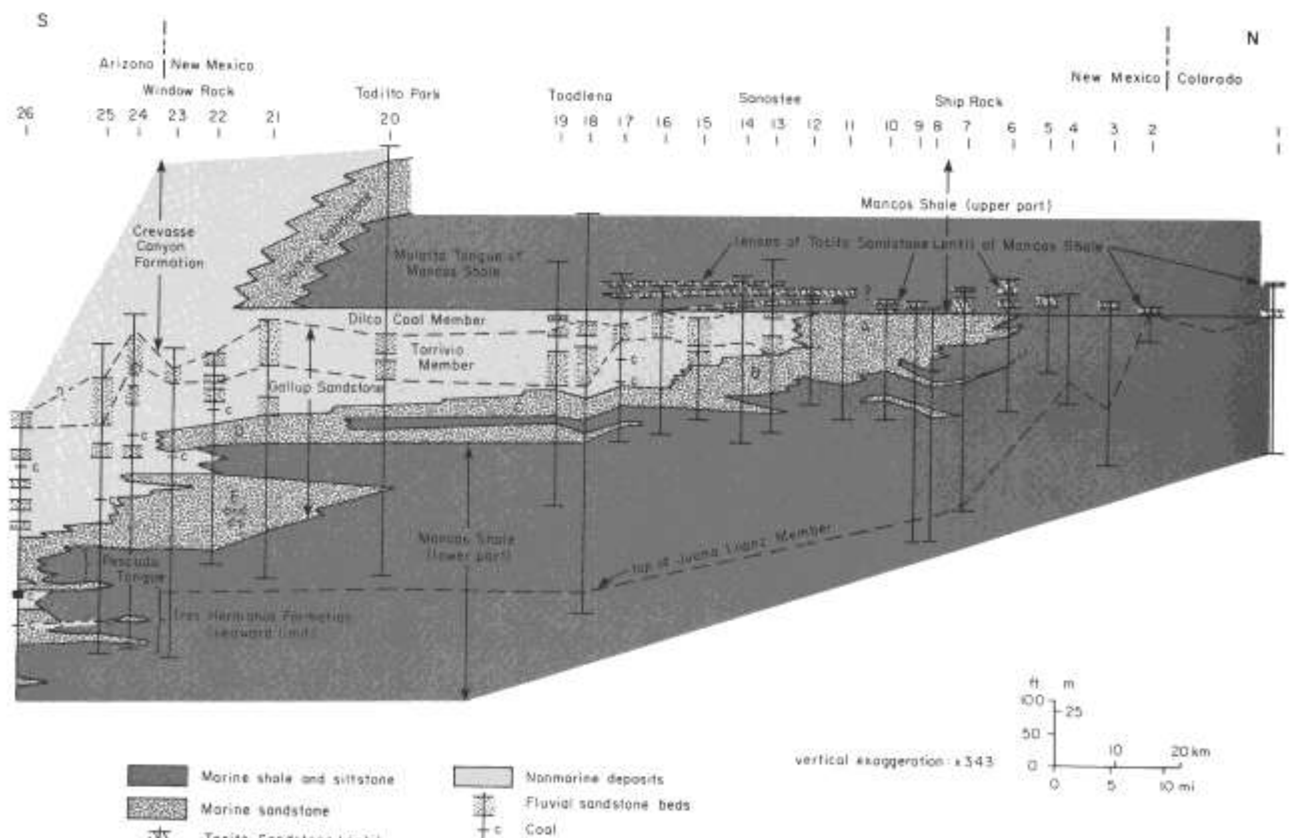

FIGURE 15—STRATIGRAPHIC CROSS SECTION ALONG WEST SIDE OF SAN JUAN BASIN (MODIFIED FROM MOLENAAR, 1973); see fig. 10 and table 7 for location of section and/or control points.

Gallup or Tres Hermanos nomenclature will no longer apply because the defining criteria placed on the Gallup Sandstone and Tres Hermanos Formation can no longer be applied. In those areas, nonmarine Cretaceous strata above the Mancos Shale will be called the Moreno Hill Formation (fig. 13; McLellan and others, this volume). In this same area, the shoreface and coastal barrier sandstone complex above the Mancos Shale, known as the Atarque Sandstone Member of the Tres Hermanos Formation in much of the Acoma and Zuni Basins, is raised to formation rank and called the Atarque Sandstone.

In areas where the marine shale of the Pescado and D-Cross Tongues pinches out or grades laterally into shoreface sandstones or nonmarine rocks, the stratigraphic nomenclature for the sequence is arbitrary and could be either Gallup, Tres Hermanos, or Atarque. The terminology for the inter-tonguing lithologies in these transitional areas, which are probably small, might best be chosen by the geologist investigating those particular areas.

One area where the landward termination of the Pescado Tongue can be traced is in the outcrop belt in Arizona west of Gallup between control points 25 and 26 (figs. 10 and 15). There, marine shale of the Pescado Tongue grades laterally into a complex of tidal-channel(?) sandstone and thin shoreface sandstone units.

The pinchout of the Pescado Tongue as diagrammatically shown in fig. 13 occurs largely in areas in which Cretaceous rocks are eroded or are covered by Tertiary sedimentary and volcanic rocks of the Zuni Plateau. In addition, except for possibly a small part, the Moreno Hill Formation is older than the Crevasse Canyon Formation. Late Tertiary and Holocene erosion has largely removed Crevasse Canyon equivalent and younger strata in west-central and southwest New Mexico and adjacent Arizona. Thus, these units have natural geographic boundaries as well as meaningful stratigraphic limits in most of the area.

The part of the Mancos Shale between the Tres Hermanos Formation or the Atarque Sandstone and the Twowells Tongue of the Dakota Sandstone will be called the Rio Salado Tongue of the Mancos Shale. See Hook and others (this volume) for details.

In addition to showing relationships of overlying and underlying units, fig. 18 shows the correlation of the Gallup Sandstone into the Puertecito and D-Cross Mountain areas in the southern Acoma Basin (control points 57 and 58A). Winchester (1920) applied the name "Gallego Sandstone" in that area to a prominent sandstone unit that is now correlated with the Gallup. Although the Gallego name predates the Gallup Sandstone name, the latter name is well established in the literature and, thus, should be the accepted name. Therefore, it is herein recommended that the name "Gallego Sandstone" be abandoned.

In addition to correlating the Gallup Sandstone and associated units over wide areas, Molenaar (1973, 1974) de-

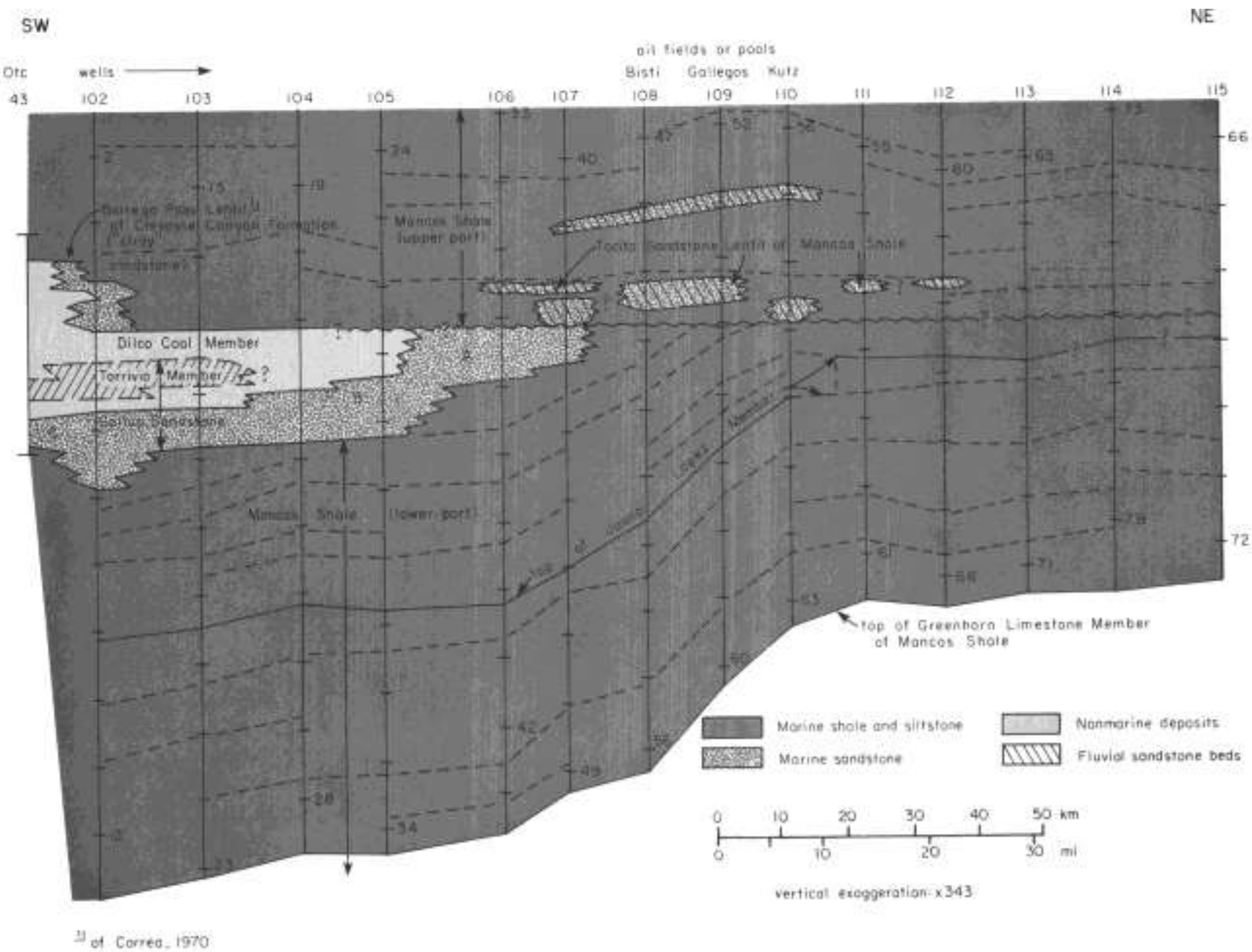

FIGURE 16—SUBSURFACE STRATIGRAPHIC CROSS SECTION ACROSS CENTRAL SAN JUAN BASIN SHOWING RELATIONSHIPS OF GALLUP SANDSTONE TO OLDER AND YOUNGER STRATA. Dashed lines are time-marker beds—bentonites and calcareous or silty zones. Well depths are in hundreds of ft (modified from Molenaar, 1973). See fig. 10 and table 7 for location of section and/or control points.

scribed many of the lithologic details of the Gallup. He described the Gallup as being of both deltaic and nondeltaic origin. On the southeast side of the San Juan Basin where few, if any, channel sandstones occur, the Gallup is inferred to be nondeltaic. The Gallup seems to represent a uniformly prograding strandplain or barrier-bar sequence. On the west side of the San Juan Basin, however, many channel sandstone units occur in the complex and parts of the Gallup are deltaic. A wave-dominated delta system is indicated by the uniformly thick coastal-barrier sandstones and the dominance of longshore current crossbedding in the upper shore-face sandstones. The deltaic lobes probably did not extend far beyond the normal shoreline trend. Molenaar (1973, 1974) also showed that the total Gallup Sandstone could be divided into several locally mappable regressive shoreface sandstone units and that these units progressively overlap each other to the northeast. The lower sandstone units are separated by transgressive shale tongues, and the upper units can be distinguished from underlying units by an abrupt rise in stratigraphic position to the northeast. The different sandstone units that were designated in descending order, A to F (Molenaar, 1973), are shown in the cross sections (figs. 13-18) and in the reference section (figs. 11 and 12). Sandstone units A, B, and C replace the nonmarine part of the reference section to the northeast (figs. 15 and 16). On the southeast side of the San Juan Basin, sandstones B and C are not separated by abrupt stratigraphic rises but, as described above, seem to represent a uniformly prograding strandplain sequence (fig. 17; Molenaar, 1974, p. 256).

The Gallup ranges in thickness from almost 400 ft (122 m) in the Gallup area to 0 ft approximately 60 mi (97 km) to the northeast where the Gallup pinches out or is truncated (figs. 10 and 16). Younger transgressive sandstone lentils that overlie the regressive Gallup or are present in areas seaward of the pinchout of the Gallup (figs. 15-17) have been included in the Gallup by Beaumont, Dane, and Sears (1956). These sandstone lenses, which are separable from and are genetically unrelated to the Gallup Sandstone, should not be included in the Gallup (Molenaar, 1973, p. 102). Fassett and Jentgen (1978, p. 236) and Fassett (1981) recommended that the original name "Tocito Sandstone Lentil of the Mancos Shale" that was introduced by Reeside (1924, p. 9) be reinstated for these sandstone bodies. Their nomenclature is used here. Except for Hospah field, all of the so-called "Gallup" oil fields or pools in the San Juan Basin produce from the Tocito Sandstone Lentil or rocks other than the true Gallup (fig. 10). The relationship of these sandstone units to the regressive Gallup is shown and described by Molenaar (1973, 1974). Figs. 15, 16, and 17 show these relationships.

Age

Fauna are generally sparse in the Gallup. The only fossil found in the principal reference section was an undiagnostic inoceramid in the lower part of the shale tongue just above the E sandstone bed. Because the Gallup Sandstone is largely a prograding sequence of time-transgressive sandstone units, the oldest marine part is at its landward or southwest extent, and the youngest part is at its seaward or northeast extent. Whether or not the Torrivio Member, the upper fluvial sand-

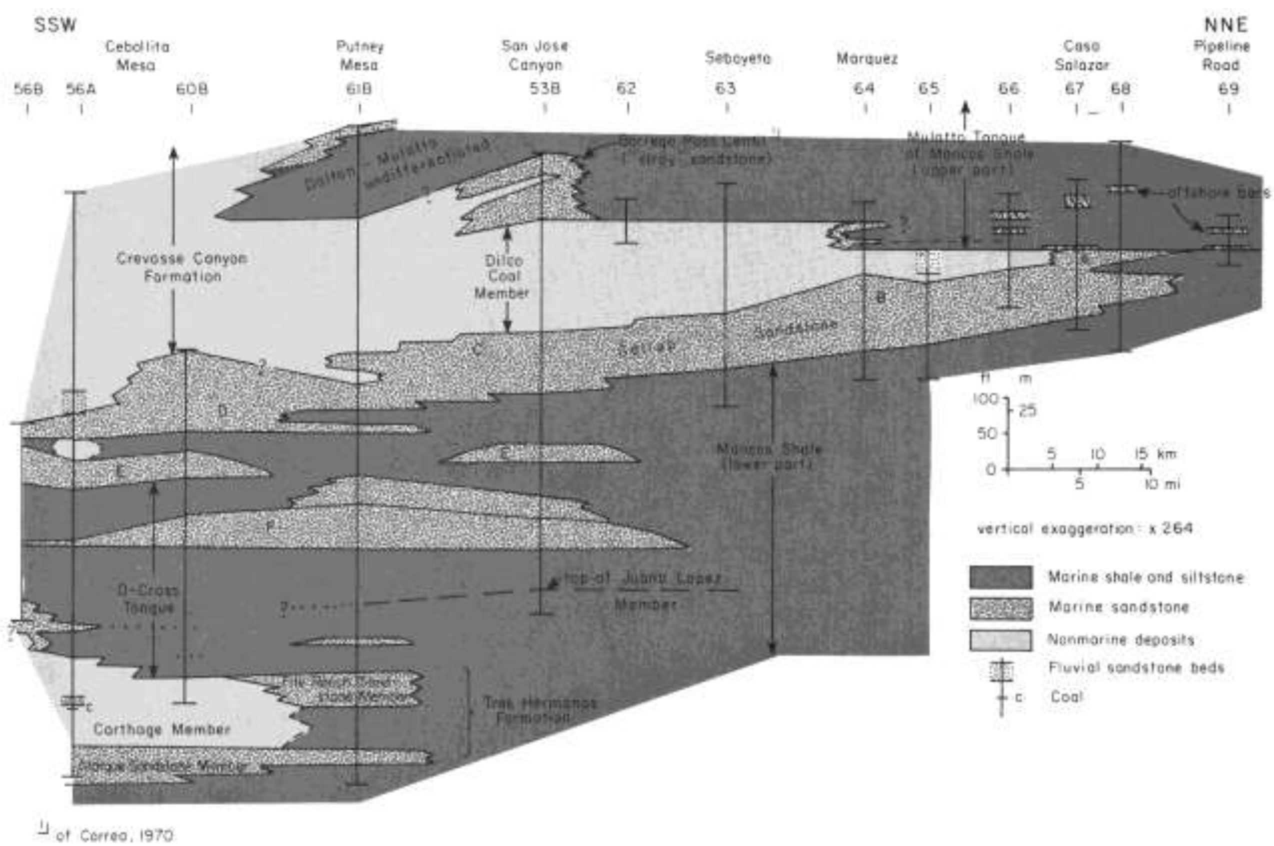

FIGURE 17—STRATIGRAPHIC CROSS SECTION FROM WESTERN ACOMA BASIN TO SOUTHEAST SAN JUAN BASIN (REVISED FROM MOLENAAR, 1974); see fig. 10 and table 7 for location of section and/or control points.

stone, is time-transgressive, however, cannot be determined at this time. Its stratigraphic position suggests that it is also younger to the north or northeast (figs. 13 and 15).

The oldest age-diagnostic fossils collected from the Gallup were *Lopha lugubris* and *Inoceramus dimidius* from the basal part of the F sandstone in the Horsehead Creek area (control point 34, fig. 13). Certainly, the Gallup would be somewhat older to the south where the Pescado Tongue pinches out as shown in fig. 13. However, fossils collected from the Pescado Tongue were the same as those mentioned above (see sheet 1 of Hook, Molenaar, and Cobban, this volume, in back pocket). At the present time, this fossil zone cannot be refined any further.

The youngest fossil collected from the Gallup Sandstone of this report (excluding the Tocito Sandstone Lentil or "transgressive Gallup") was reported by Molenaar (1973, p. 100). He reported early forms of *Inoceramus erectus* from the regressive Gallup Sandstone near its seaward pinchout (probably equivalent to the A sandstone bed) in sec. 14, T. 13 N., R. 1 W. on the southeast side of the San Juan Basin. (All of the fossils noted above were identified by W. A. Cobban of the U.S. Geological Survey and/or S. C. Hook then with the New Mexico Bureau of Mines and Mineral Resources and now with Getty Oil.)

Based on this fossil evidence, the Gallup Sandstone ranges in age from early late Turonian to early Coniacian (Late Cretaceous).

Regional correlations

The Gallup Sandstone has been correlated as far southeast as the Carthage area 15 mi (24 km) southeast of Socorro (figs. 10 and 18; Molenaar, 1974, p. 257). Molenaar (1973, p. 106) stated that the upper Gallup Sandstone (Gallup Sandstone of the present paper) is also present in the Caballo Mountains near Truth or Consequences and in the southern San Andres Mountains northeast of Las Cruces. Outside of New Mexico and adjoining northeasternmost Arizona, however, the Gallup has few if any correlative sandstone units. To the northwest in the Black Mesa area of northern Arizona and the Kaiparowits—Henry Mountains region of southern Utah, the Gallup interval is represented by an unconformity or hiatus (Peterson and Kirk, 1977, p. 169-170). Farther north, the Ferron and Frontier Sandstone Members of the

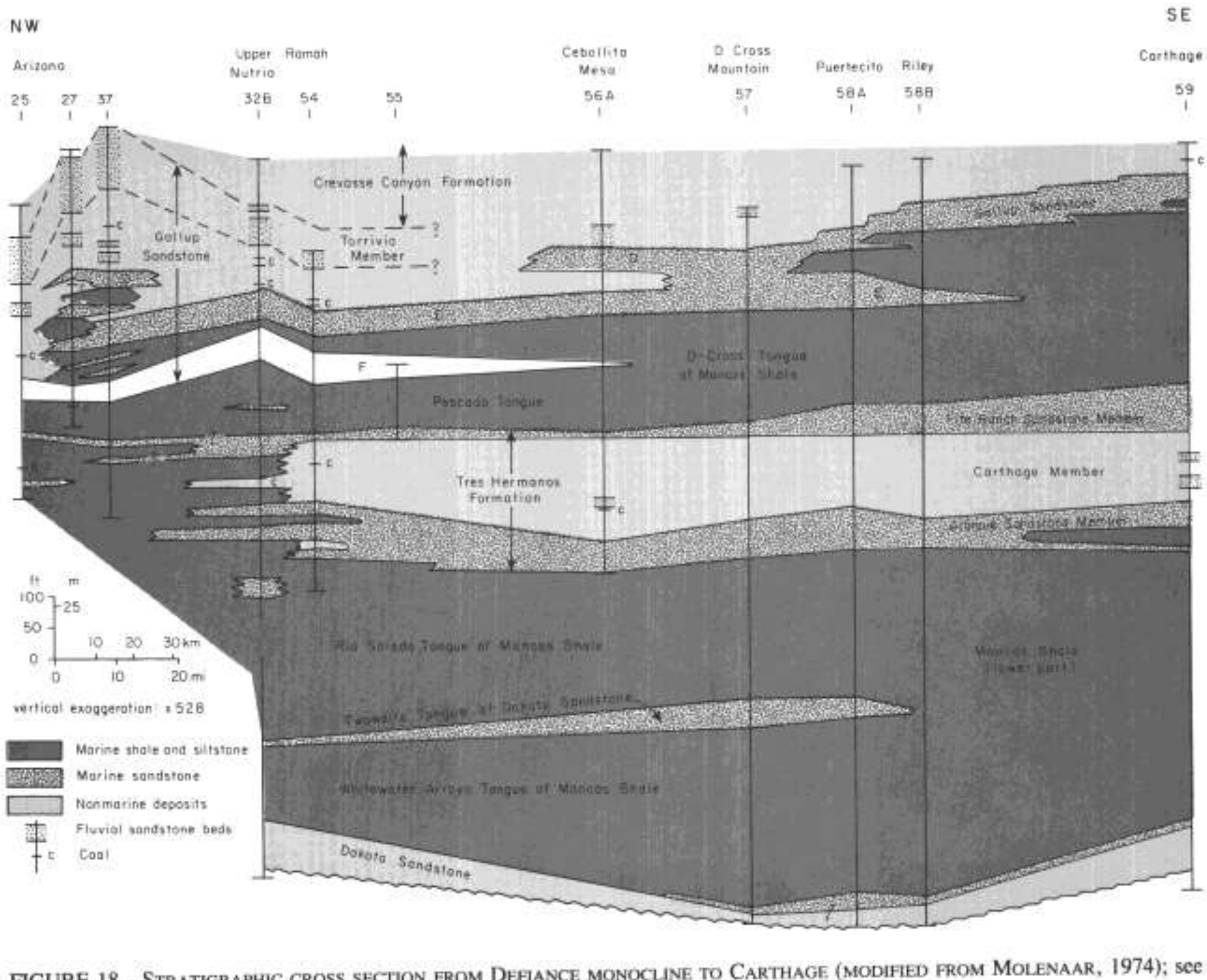

FIGURE 18—Stratigraphic cross section from Defiance monocline to Carthage (modified from Molenaar, 1974); see fig. 10 and table 7 for location of section and/or control points.

Mancos Shale of northeast Utah are overlain by a shale which in its basal part is Juana Lopez (early late Turonian) in age (Molenaar, 1975, p. 191). The lower part of this shale is probably equivalent to the Pescado or D-Cross Tongue. However, fauna of Coniacian Age occur approximately 100 ft (30 m) above the base of the shale, and no perceptible break in sedimentation in the intervening strata exists. Thus, the Gallup Sandstone probably was restricted in areal extent to parts of New Mexico, northeast Arizona, and possibly southern Utah prior to Tertiary and Holocene erosion. The Gallup is a regressive clastic wedge derived from an active provenance in southern or southwest Arizona at a time when the land area bounding the west side of the Western Interior seaway farther north was generally subdued and was relatively inactive as a major source area (Molenaar, 1973, p. 106).

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MIDDLE TURONIAN AND YOUNGER CRETACEOUS ROCKS, NORTHERN SALT LAKE COAL FIELD, CIBOLA AND CATRON COUNTIES, NEW MEXICO

by Marguerite McLellan, Laura Haschke, Laura Robinson, M. Deveraux Carter, and Antoinette Medlin,
U.S. Geological Survey, Denver, CO, and Reston, VA

Introduction

The Cretaceous rocks in the Salt Lake coal field of western New Mexico that formerly were lumped as the Mesaverde Group are revised to include, in ascending order, the Atarque Sandstone (of formation rank in the Salt Lake coal field) and the Moreno Hill Formation (new name). These names replace previously used less definitive terminology. Recent geologic mapping and stratigraphic and paleontological studies allow local and regional understanding of the marginal marine sandstone—the Atarque Sandstone—that Pike (1947) named Atarque Member of the Mesaverde Formation for exposures northeast of Atarque, and of the nonmarine coal-bearing Moreno Hill Formation. This paper describes the stratigraphy and lithology of these units which formerly were referred to as the Mesaverde Group, undivided (Dane and Bachman, 1965). These names will be applied to map units in the Salt Lake coal field and adjoining areas.

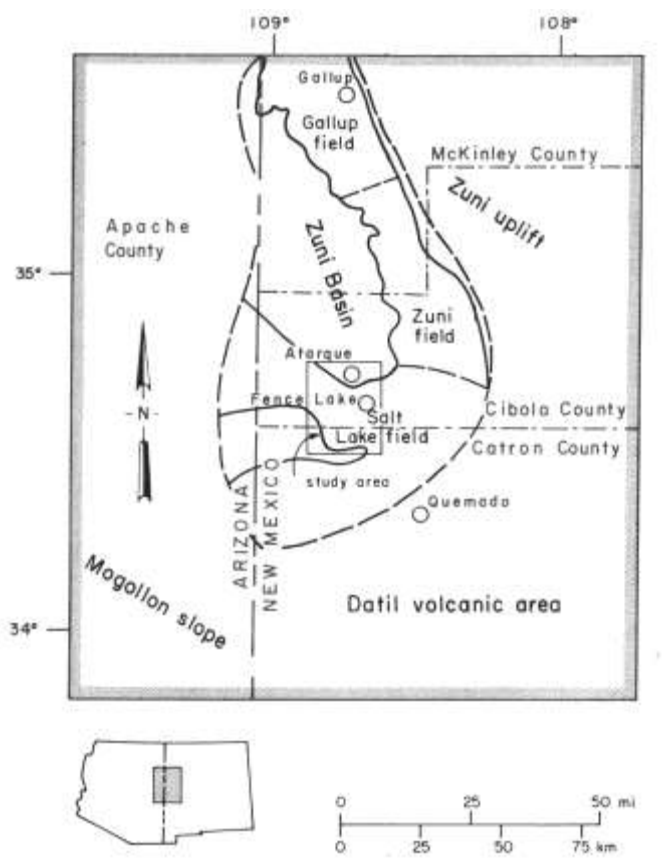

FIGURE 19—INDEX MAP OF NORTHERN SALT LAKE COAL FIELD AREA SHOWING STUDY AREA, COAL FIELDS, AND SURROUNDING GEOLOGIC FEATURES; MODIFIED FROM TRUMBULL (1960).

Geologic study and mapping of the Moreno Hill, Fence Lake SW, Fence Lake, and Rincon Hondo 7 1/2-min quadrangles, Cibola and Catron Counties, New Mexico (figs. 19 and 20), were done by the U.S. Geological Survey during the summers of 1978, 1979, and 1980 (McLellan and others, 1983; Landis and others, in preparation; McLellan, Robinson, and Haschke, 1983; and McLellan, Haschke, and Robinson, 1982). This work is part of a cooperative study of eight 7 1/2-min quadrangles in the Zuni Basin and Salt Lake coal field (fig. 19) being made by the New Mexico Bureau of Mines and Mineral Resources and the U.S. Geological Survey.

The Atarque and Moreno Hill rocks in the Salt Lake coal field previously had not been studied in detail.

Thirty-three stratigraphic sections of Cretaceous and Tertiary rocks were measured and described on the south- and east-facing cliffs of the Zuni Plateau and Santa Rita Mesa in the Moreno Hill and Fence Lake SW quadrangles (fig. 20). Seven of these measured sections are shown as a west-to-east cross section (fig. 21). Fossils were collected from the lower parts of the sections and were identified by W. A. Cobban, Norman F. Sohl, and G. Edward Lewis of the U.S. Geological Survey.

Geologic setting

The area of most detailed stratigraphic study is approximately 6 mi southwest of Fence Lake, New Mexico (fig. 19). Rocks of Triassic through Quaternary age are present in the area. The highest topographic features, the Zuni Plateau and Santa Rita Mesa, which are about 7,500 ft (2,273 m) in elevation, are covered by pinion and juniper trees and are dissected by many canyons. Below approximately 6,900 ft (2,091 m), the land supports sparse grass, cactus, sage brush, and tumbleweed.

The stratigraphic units described in this paper are underlain by the Rio Salado Tongue (Hook and others, this volume) of the Mancos Shale of Late Cretaceous (late Cenomanian to middle Turonian) age and are overlain unconformably by fluvial rocks of probable Miocene age. Only 200 ft (61 m) of Atarque and Moreno Hill remain below the cemented Tertiary gravel of the Fence Lake Formation (McLellan and others, 1982) in the westernmost section (section A, figs. 20 and 21) measured in Moreno Hill quadrangle, in sec. 31, T. 5 N., R. 19 W. The Atarque and Moreno Hill rocks dip less than 1° to the northeast and are offset by a few faults.

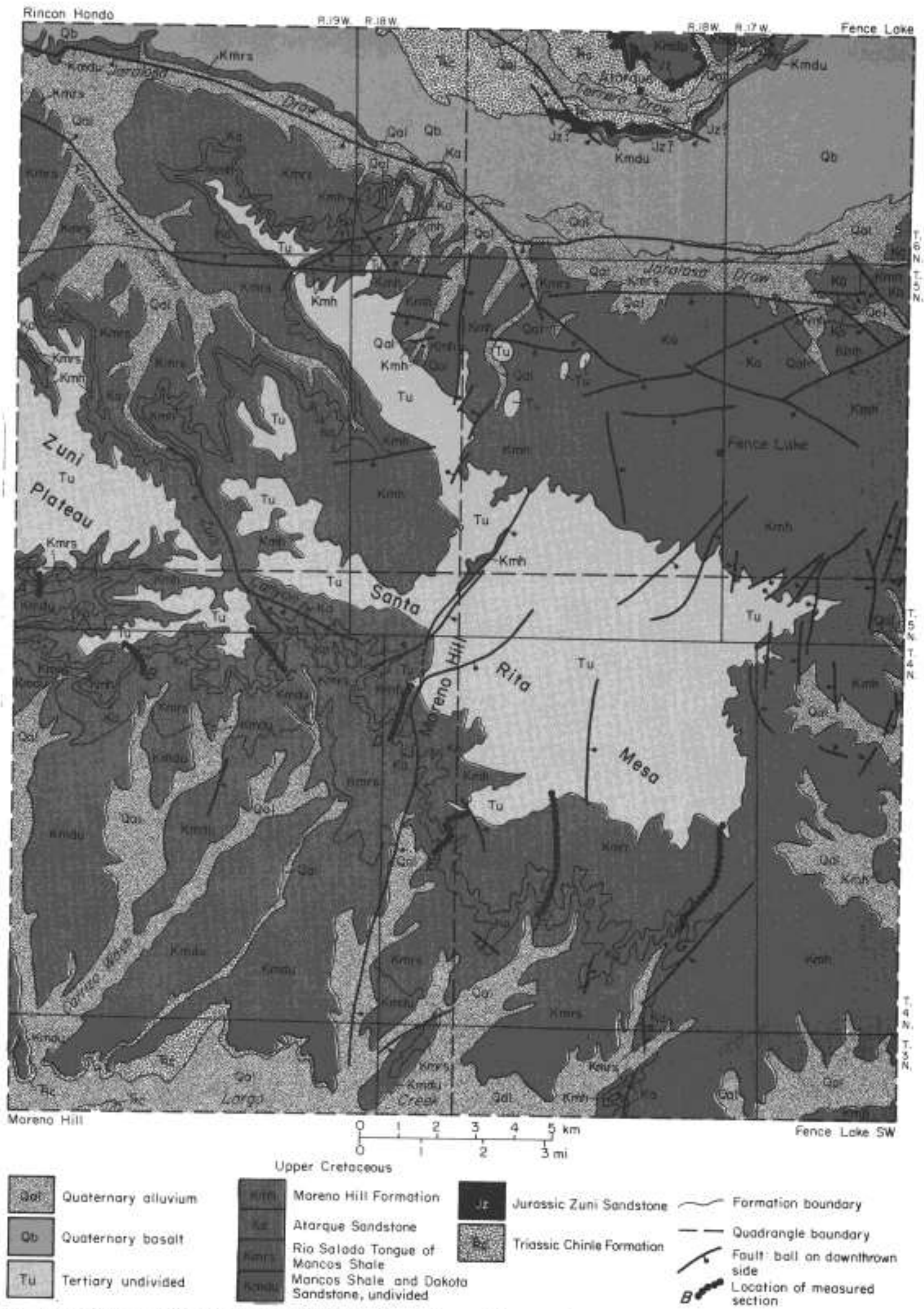

FIGURE 20—GENERALIZED GEOLOGIC MAP OF MORENO HILL, RINCON HONDO, FENCE LAKE, AND FENCE LAKE SW QUADRANGLES, showing locations of measured sections appearing in cross section (fig. 21); base from U.S. Geological Survey 1:24,000 topographic maps.

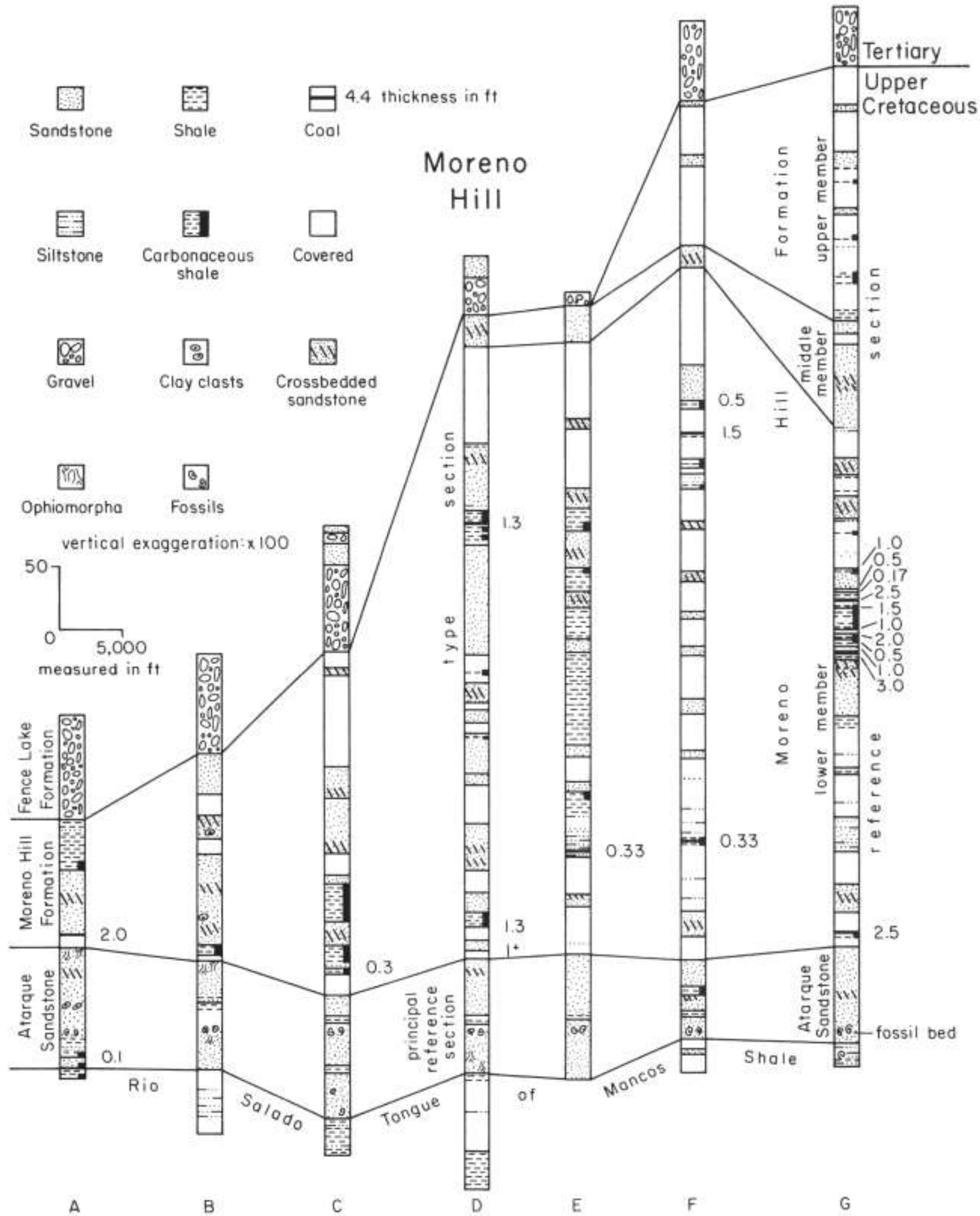

FIGURE 21—Representative columnar sections in Moreno Hill area showing Atarque Sandstone and Moreno Hill Formation; localities of sections shown on geologic map (fig. 20).

Proposed stratigraphic names

A type section for the Moreno Hill Formation (section D, figs. 20 and 21) and a principal reference section for the Atarque Sandstone have been established at Moreno Hill, secs. 7 and 6, T. 4 N., R. 18 W., where 617 ft (187 m) of Atarque Sandstone and Moreno Hill Formation were measured. The lower 98 ft (30 m) of these rocks, belonging to the Atarque, consists of regressive, shallow-water-marine, mostly flat-bedded sandstones, siltstones, and shale. Fossils were collected and identified from these rocks. The upper 519 ft (157 m), belonging to the Moreno Hill, is composed of fluvial crossbedded sandstones, siltstones, shales, carbonaceous shales, and thin coal beds. This measured section has close to the maximum amount of Atarque and Moreno Hill rocks exposed within the Moreno Hill quadrangle.

Rocks now named Atarque Sandstone and Moreno Hill Formation, previously referred to as Mesaverde in the Zuni—Salt Lake area, are similar in appearance to those known as Mesaverde in the Gallup area; however, they are much lower in the stratigraphic section and are older. Moreover, a much greater proportion of these rocks is of fluvial origin. In order to better describe the lithology and stratigraphic relations of these rocks, we are dividing them on the basis of origin and revising and naming them.

Atarque Sandstone

The lower 98 ft of measured section D, which is of shallow-water-marine origin, is assigned to the Atarque Sandstone. This name is a revision of the upper contact of the Atarque and a change of stratigraphic rank for the rocks that Pike (1947, p. 13, 35; pls. 11, 12) named the Atarque Member of the Mesaverde Formation. He applied the name to all rocks from the base of the lowest regressive sandstone of the Mesaverde to the base of what he called the marine-deposited Horsehead Tongue of the Mancos Shale in an area approximately 6-8 mi (10-13 km) northeast of the abandoned village of Atarque and 17-19 mi (27-30 km) northeast of our principal reference section. Later, Molenaar (1973, p. 94-96) used the name Atarque Member for all rocks from the base of the lowest regressive sandstone of the Mesaverde to the base of the gray marine-deposited Pescado Tongue of the Mancos Shale. These usages are more fully explained by Hook and others in this publication. Sandstones assigned to the Atarque represent a regressive marine sequence deposited northeastward in the Cretaceous seaway in the vicinity of the present-day Zuni and San Juan Basins, as well as in Acoma Basin, and near Carthage and Truth or Consequences.

As proposed by Hook and others (this volume), the Atarque Member would be defined as the lower part of the Tres Hermanos Formation. The Tres Hermanos is bounded by the underlying marine Rio Salado Tongue of the Mancos Shale and the overlying marine-deposited Pescado Tongue of the Mancos Shale in Zuni Basin. The Pescado Tongue represents a marine transgression that did not extend as far south and west as the Fence Lake area (figs. 19 and 20), and consequently the Tres Hermanos Formation is not recognized in that area and farther southwestward. However, the marine sandstone sequence that forms the Atarque Member farther northeastward is readily distinguishable in the area of fig. 20. Consequently, the name Atarque Sandstone as a unit of formation rank is applied to these rocks, and a principal reference section (D, fig. 21) is designated in sec. 7, T. 4 N., R. 18 W. (table 9).

The base of the Atarque Sandstone is at the base of the lowest very fine grained flat-bedded massive sandstone that is immediately above a transition zone of brownish-gray to light-olive-gray very slightly micaceous shale interbedded with thin yellowish-gray siltstones and silty sandstones in the upper Rio Salado Tongue of the Mancos Shale. The top of the Atarque is placed at the top of the uppermost flat-bedded to very low angle crossbedded sandstone, which is intensely burrowed in most places, and at the base of a dusky-brown carbonaceous shale. Along the Zuni Plateau—Santa Rita Mesa escarpment, the Atarque ranges from 25 ft to 120 ft (8 m-36 m) in thickness. Anderson (1981) reported thickness ranges of 25-55 ft (8-17 m) to the west in the Cantaralo Spring quadrangle.

The Atarque Sandstone was deposited as a series of coastal-barrier bars and it conformably overlies the brownish-gray shale of the marine Rio Salado Tongue of the Mancos Shale. The zone of transition between the two formations is one of very thin bedded yellowish-gray (5 Y 7/2) siltstones interbedded with yellowish-gray (5 Y 7/2) shale. The Atarque thickens in the Cerro Prieto and The Dyke quadrangles (Campbell, 1981) to the east by the addition of sandstone beds at the base and at the top. Eastward from the principal reference section, in the Fence Lake SW quadrangle, the marine sandstone beds dip into the subsurface so that the Atarque is not exposed east of T. 4 N., R. 18 W.

The east-west section (fig. 21) was prepared with the top of the uppermost fossiliferous zone as the datum. Fossils

TABLE 9—Reference section of Atarque Sandstone, southwest side of Santa Rita Mesa, Cibola County, New Mexico, beginning in SW$^{1}/_{4}$ sec. 7, T. 4 N., R. 18 W., Moreno Hill 7$^{1}/_{2}$-min quadrangle.

Unit	Lithology	Thickness ft	Thickness m
	Top of *Atarque Sandstone:* base of Moreno Hill Formation		
11	Sandstone, grayish-orange (10 YR 7/4), fine-grained, mostly crossbedded with upper 1 ft flat-bedded and bioturbated.	25.4	*7.7*
10	Sandstone, yellowish-gray (5 Y 7/2), very fine grained, calcareous, thin-bedded.	1	*0.3*
9	Sandstone, grayish-orange (10 YR 7/4), very fine grained, flat-bedded, nonresistant.	19	*5.8*
8	Sandstone, pinkish-gray (5 YR 8/1), very fine grained.	1	*0.3*
7	Shale.	9.4	*2.9*
6	Sandstone, pinkish-gray (5 YR 8/1), very fine grained, fossiliferous.	1	*0.3*
5	Sandstone, light-gray (N 6), very fine grained, calcareous.	1.6	*0.5*
4	Sandstone, flat-bedded; thin shale layers and *Ophiomorpha* burrows at the base.	22.5	*6.9*
3	Shale and interbedded very fine grained sandstone, yellowish-gray (5 Y 7/2).	1.5	*0.5*
2	Sandstone, grayish-orange (10 YR 7/4), very fine grained, massive.	10	*3.0*
1	Sandstone, grayish-orange (10 YR 7/4), very fine grained, interbedded with shale, light-olive gray (5 Y 5/2); containing *Ophiomorpha* burrows.	5.5	*1.7*

identified from this zone include the following pelecypods: *Aphrodina* sp., *Corbula sp* . , *Crassostrea soleniscus* (Meek), *Crassostrea sp., Curvostrea* sp., *Cymbophora emmonsi* (Meek), *Cymbophora? sp., Cymbophora utahensis* (Meek), *Cyprimeria* cf. *C. cyprimeriformis* (Stanton), *Cyprimeria* sp., *Exogyra* cf. *E. oxyntas* (Coquand), *Inoceramus (Mytiloides)* sp., *Modiolus* sp., *Mytiloides* sp., *Ostrea* sp., *Phelopteria gastrodes* (Meek), *Pleuriocardia pauperculum* (Meek), and *Veniella mortoni* Meek and Hayden; the following gastropods: *Cassiope* sp., *Cryptorhytis?* sp., *Cryptorhytis* n. sp., *Gyrodes* cf. *G. depressa* (Meek), *Gyrodes depressus* (Meek), *Gyrodes* sp., and *Pyropsis* sp.; *Ophiomorpha* sp.; and parts of the centrum of a vertebra of a plesiosaur, genus and species indeterminate.

These fossils are from either shallow-water-marine or brackish-water environments. In the western part of the study area, the Atarque has been dated as middle Turonian (W. A. Cobban, personal communication, 1981).

Moreno Hill Formation

The Moreno Hill Formation, herein named, is the nonmarine sequence that is stratigraphically above the Atarque Sandstone and is south of the pinchout of the Pescado Tongue of the Mancos Shale.

The upper 519 ft (157 m) of nonmarine rocks in measured section D is assigned to the Moreno Hill Formation and is designated as the type section. The Moreno Hill Formation is as much as 715 ft (217 m) thick in the study area, although in some places it has been removed by pre-Tertiary through Holocene erosion. To the east in the Cerro Prieto and The Dyke quadrangles, the formation is 768 ft (233 m) thick, lying unconformably beneath the Tertiary sediments (Campbell, 1981). In most places the base of the Moreno Hill is the base of the dusky-brown carbonaceous shale overlying the uppermost flat-bedded sandstone of the Atarque. In a few places the basal carbonaceous shale of the Moreno Hill was truncated so that the lowest steeply crossbedded fluvial sandstone of the Moreno Hill lies directly on the flat-bedded or very low angle crossbedded Atarque Sandstone. The top of the Moreno Hill in the mapped area is the top of the paleyellowish-orange sandstones and brownish-gray carbonaceous shales that are unconformably overlain by pinkish-gray Tertiary gravels and sandstones. The Moreno Hill includes shale, carbonaceous shale, sandstones, siltstones, and thin coal beds. The sandstones are very pale orange, grayish orange, light brown, and pale yellowish brown, very fine grained to very coarse grained, poorly sorted, subangular, and, in most places, steeply crossbedded. The sandstones commonly contain clay clasts, or molds of such, and carbonaceous matter. These sandstones are somewhat discontinuous and are considered to be fluvial channel and splay deposits.

The Moreno Hill is laterally equivalent in part to the Tres Hermanos Formation, Pescado Tongue of the Mancos Shale, and Gallup Sandstone (see Hook and others, this volume). The upper part of the Moreno Hill possibly is laterally equivalent to the lowest part of the Crevasse Canyon Formation (Hook and others, this volume). The southwestward pinch-out of the Pescado, however, requires a change in terminology for the Cretaceous rocks overlying the Rio Salado Tongue of the Mancos Shale in the area of fig. 20 and southwestward.

The shales are mostly soft olive gray, pale brown, or brownish gray and carbonaceous and are interbedded with light-olive-gray shale and were probably deposited in back-bay swamps or in lagoons.

Thin coal beds are interbedded with brownish-black, very coaly shale beds within the carbonaceous shales. Some of the coal beds contain thin layers of altered volcanic ash (tonsteins), and some of the coals are underlain by rooted zones. Analyses of cores of these coal beds from drill holes in the study area indicate that the apparent rank of these coals is high-volatile C bituminous.

The Moreno Hill Formation has been divided into three members: a lower member, a middle member, and an upper member. At the type section, the formation is 519 ft (157 m) thick and is composed of the lower two members (table 10).

TABLE 10—Type section of Moreno Hill Formation, southwest side of Santa Rita Mesa, Cibola County, New Mexico, beginning in N$^{1}/_{2}$ sec. 7, T. 4 N., R. 18 W., Moreno Hill 7$^{1}/_{2}$-min quadrangle.

Unit	Lithology	Thickness ft	*m*
	Top of lower member of *Moreno Hill Formation;* base of middle member.		
43	Covered.	84	*25.6*
42	Sandstone.	5	*1.5*
41	Sandstone, grayish-orange (10 YR 7/4), medium-grained, subangular, crossbedded.	10	*3.0*
40	Sandstone, very pale orange (10 YR 8/2), medium-grained, nonresistant.	4	*1.2*
39	Sandstone, grayish-orange (10 YR 7/4), medium-grained, subangular, massive; with clay galls and scattered red stains.	25	*7.6*
38	Siltstone, yellowish-gray (5 Y 8/1), sandy, carbonaceous.	5	*1.5*
37	Shale, olive-gray (5 Y 4/1), carbonaceous.	11.5	*3.5*
36	Coal.	1	*0.3*
35	Shale, dark reddish-brown (10 R 3/4), carbonaceous.	0.5	*0.2*
34	Interbedded siltstone, sandy; and shale, carbonaceous.	15	*4.6*
33	Sandstone, brownish-gray (5 YR 4/1), calcareous, hard.	1	*0.3*
32	Sandstone, grayish-orange (10 YR 7/4), very fine grained, massive.	15	*4.6*
31	Sandstone, pale-yellowish-brown (10 YR 6/2), very fine grained, carbonaceous.	3	*0.9*
30	Siltstone, pale-yellowish-brown (10 YR 6/2), hard, sandy, fissile, carbonaceous.	7	*2.1*
29	Interbedded siltstone and carbonaceous shale.	5	*1.5*
28	Sandstone, grayish-orange (10 YR 7/4), fine-grained, carbonaceous, gypsiferous.	5	*1.5*
27	Interbedded siltstone and carbonaceous shale.	13	*4.0*
26	Siltstone, carbonaceous.	2	*0.6*
25	Siltstone, sandy.	5	*1.5*
24	Siltstone.	1	*0.3*
23	Shale, medium-dark-gray (N 4), carbonaceous.	4	*1.2*
22	Siltstone, light-olive-gray (5 Y 5/2), sandy; with carbonaceous material (roots).	9	*2.7*
21	Shale, carbonaceous.	16	*4.8*

TABLE 10 (con't)

Unit	Lithology	Thickness ft	Thickness *m*
20	Covered.	15	*4.6*
19	Shale, brownish-gray (5 YR 4/1), carbonaceous, grading into medium-dark-gray (N 4) carbonaceous shale.	2	*0.6*
18	Covered.	7.5	*2.3*
17	Sandstone, grayish-orange (10 YR 7/4) to very pale orange (10 YR 8/2), very fine grained, calcareous, crossbedded; crossbeds dip 10° N.	17	*5.2*
16	Covered.	6	*1.8*
15	Sandstone, moderate-yellowish-brown (10 YR 5/4), very fine grained, thin-bedded, fractured.	4	*1.2*
14	Sandstone, pale-yellowish-orange (10 YR 8/6), very fine grained.	6	*1.8*
13	Covered.	8	*2.4*
12	Sandstone, slabby.	3	*0.9*
11	Shale, carbonaceous.	2	*0.6*
10	Covered.	28	*8.5*
9	Sandstone,grayish-orange (10 YR 7/4), medium-grained, subrounded, calcareous, crossbedded; with crossbeds dipping 20° N.	5	*1.5*
8	Gravel, poorly sorted, cemented in fine-grained sandstone matrix.	3	*0.9*
7	Shale, mostly covered.	33	*10.1*
6	Sandstone.	6	*1.8*
5	Shale, mostly covered.	5	*1.5*
4	Sandstone, grayish-orange (10 YR 7/4), fine-grained, crossbedded; with weathered clay gall cavities.	23	*7.0*
3	Shale, mostly covered.	19	*5.8*
2	Sandstone, pale-yellowish-brown (10 YR 6/2), very fine grained.	16	*4.8*
1	Shale, carbonaceous; contains two 1-ft (.3 m) coal beds.	39	*11.9*
	Thickness of lower member of *Moreno Hill Formation.*	494.5	*150.7*
	Overlies unit 11 at top of Atarque Sandstone at reference section of Atarque Sandstone.		

The lower member is predominantly carbonaceous shale with fluvial sandstones and minor coal beds. The carbonaceous shales thin westward from the type section and in the west half of Moreno Hill quadrangle, fluvial sandstones are predominant. Farther westward, however, in the Cantaralo Spring quadrangle, shales and coaly beds make up most of the lower member (Anderson, 1981). Within 20 ft (6 m) of the base is a persistent coal bed that, where seen along the south side of Zuni Plateau and Santa Rita Mesa, is about 2.5 ft (.8 m) thick. Shaler (1907, p. 421), however, reported two coal beds of 3.5 and 4 ft (1 and 1.2 m) separated by 6 ft (2 m) of shale within this zone in sec. 1 or 2, T. 4 N., R. 19 W. In some places erosion has scoured through this coal bed and through the carbonaceous shales in which it occurs, so that the lowest Moreno Hill sandstone lies immediately on the Atarque Sandstone. Eastward in Fence Lake SW quadrangle, conspicuous coal zones appear progressively higher in the lower member. In the Cerro Prieto quadrangle, east of Fence Lake SW quadrangle, two coal horizons occur, the highest zone being about 20 ft (6 m) below the middle member and the lower outcropping zone occurring above the middle of the lower member (Campbell, 1981).

The middle member is composed of massive fluvial medium- to coarse-grained crossbedded arkosic sandstones. These sandstones contain zones of 0.25-inch spheroidal iron concretions that weather and give the sandstones a reddish appearance on some exposures. To the east, the middle member becomes thicker and its sandstones form the most prominent ledges on the slopes of Santa Rita Mesa. West of R. 18 W., this member has been truncated completely and the lower member is overlain by middle Tertiary rocks. At the type section, the middle member consists of 24 ft (7 m) of pale-yellowish-orange (10 YR 8/6), medium-grained, concretionary, crossbedded sandstone containing clay galls. To the east in eastern Fence Lake SW, Cerro Prieto, and The Dyke quadrangles, the member averages 60 ft (18 m) in thickness, ranging from 40 to 80 ft (12 to 24 m; Campbell, 1981).

The upper member consists mostly of carbonaceous shales, thin fluvial sandstones, siltstones, and thin coal beds. It crops out across the eastern three-fourths of Fence Lake SW quadrangle. The upper member is especially well exposed in measured section G (figs. 20 and 21), in the south half of sec. 13, T. 4 N., R. 19 W., which we are designating as a reference section. To the west it is truncated by erosion and overlain by middle Tertiary rocks. To the east it is approximately 360 ft (109 m) thick, lying unconformably beneath the middle Tertiary sediments (Campbell, 1981); to the southeast in the Tejana Mesa quadrangle, southeast of Fence Lake SW quadrangle, 712 ft (216 m) of the upper member occurs, lying unconformably beneath the Baca Formation (Eocene; Gretchen Roybal, personal communication, 1982).

Fence Lake Formation conglomerates and sandstones of middle Tertiary, probably Miocene, age (McLellan and others, 1982) unconformably overlie the Moreno Hill Formation in the area mapped by us. Both to the north and to the west, erosion prior to deposition of these beds cut deeply into the Moreno Hill rocks so that in the western part of the Moreno Hill quadrangle less than 40 ft (13 m) of Moreno Hill Formation remains.

No fossils were found within the Moreno Hill Formation. All carbonaceous material was too broken or too worn to be identified. The lower member of the Moreno Hill is considered to be middle to late Turonian in age, inasmuch as it overlies the middle Turonian Atarque Sandstone.

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MID-CRETACEOUS MOLLUSCAN SEQUENCE AT GOLD HILL, JEFF DAVIS COUNTY, TEXAS, WITH COMPARISON TO NEW MEXICO

by Stephen C. Hook, *Getty Oil Company, Exploration and Production Research Center, Houston, Texas,*
and William A. Cobban, *U.S. Geological Survey, Denver, Colorado*

Abstract

The lower 155 ft (47 m) of the Boquillas Limestone are well exposed and exceptionally fossiliferous on Gold Hill in northern Jeff Davis County, Texas. Here, the Boquillas unconformably overlies the Buda Limestone and consists of two members: a lower, hard, flaggy limestone member, 55 ft (17 m) thick, and an upper shale and limestone member, 100 ft (30 m) thick. Molluscan fossils, chiefly inoceramids and ammonites, collected from these two members are of early Cenomanian to late Turonian age. Silicified fossils collected from the base of the Boquillas are representative of the early Cenomanian zone of *Forbesiceras brundrettei* Young. *Inoceramus arvanus* Stephenson and *I. rutherfordi* Warren, which indicate the middle Cenomanian zone of *Acanthoceras amphibolum* Morrow, were collected from several beds of limestone that occur 6-12 ft (2-4 m) above the base. *Inoceramus prefragilis* Stephenson and *Calycoceras* cf. *C. canitaurinum* (Haas), of late Cenomanian age, were collected near the middle of the flaggy member. A questionable *Nigericeras scotti* Cobban, of early Turonian age, was collected near the top of this member. Poorly preserved ammonites that may be associated with *Mytiloides mytiloides* (Mantell) occur in the basal quarter of the upper member; an early Turonian age is indicated by this assemblage. *Mammites nodosoides* (Schluter) and *Morrowites depressus* (Powell), of late early Turonian age, are abundant in most of the upper half of this member. A nodular limestone bed 11 ft (3 m) below the top of Gold Hill contains *Collignoniceras woollgari* (Mantell) and *Spathites rioensis* Powell of middle Turonian age. This bed is overlain by phosphatized pebbles and cobbles that mark a significant middle Turonian disconformity. *Prionocyclus hyatti* (Stanton), of late middle Turonian age, occurs at this pebble level and through most of the overlying shale. *Lopha lugubris* (Conrad), of earliest late Turonian age, was found on top of Gold Hill.

Introduction

Upper Cretaceous rocks assigned to the Boquillas Limestone by Brand and DeFord (1962) are well exposed on Gold Hill, 5.3 mi (8.8 km) south, 32° east of the common corner of Jeff Davis, Culberson, and Reeves Counties, Texas (fig. 22). Gold Hill, also called Yellow Hill by the local ranchers, is a relatively unvegetated, erosional remnant of Boquillas that stands in sharp color contrast to the surrounding countryside (fig. 23). The Boquillas Limestone, which is exposed on and just below Gold Hill, is 155 ft (47 m) thick and consists of two members: a lower, yellow-orange- and salmon-weathering, thin-bedded, flaggy limestone member, 55 ft (17 m) thick; and an upper, less resistant, yellow-weathering shale and limestone member, 100 ft (30 m) thick, composed of interbedded calcareous shale and limestone.

Megafossils, primarily mollusks, are abundant and generally well preserved. Megafossil collections were made from 22 separate levels in a measured section (table 11).

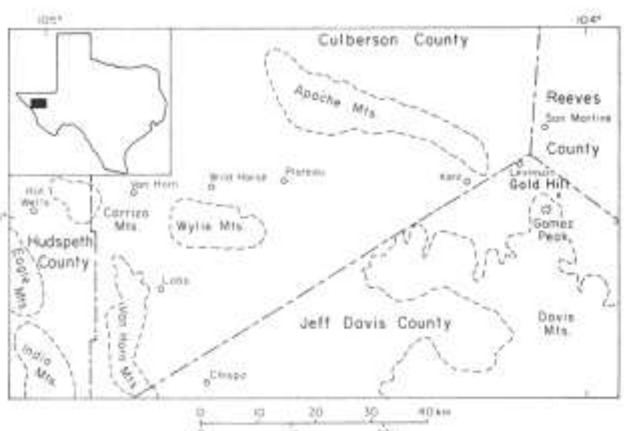

FIGURE 22—INDEX MAP OF TRANS-PECOS TEXAS SHOWING LOCATION OF GOLD HILL.

FIGURE 23—GOLD HILL, AN EROSIONAL REMNANT OF BOQUILLAS LIMESTONE, IS UNVEGETATED HILL IN CENTER OF PHOTOGRAPH. Yellow-weathering shales and limestones of upper member of Boquillas stand in sharp contrast to surrounding countryside. View is southwest toward Gomez Peak in background.

TABLE 11—Stratigraphic section at Gold Hill; measured by S. C. Hook on May 16, 1980, with additional detail added on October 15, 1980, chiefly on the south and east sides of Gold Hill, Gomez Peak 7½-min quadrangle, Jeff Davis County, Texas. A Jacob's staff and Abney hand level were used to measure these nearly flat-lying beds; fossil collections were made by Hook, Cobban, and R. E. Burkholder in May 1980 and by Hook and Cobban in October 1980.

Unit	Lithology	Thickness ft	inches	*m*
	Boquillas Limestone *Shale and limestone member* (part)			
24	Limestone, nodular, gray; weathers yellowish-brown; resistant unit; top of Gold Hill.	--	4	*0.10*
	USGS Mesozoic locality D11196: *Hemiaster jacksoni* Maury *Inoceramus* cf. *I. tenuistriatus* Nagao and Matsumoto *Pycnodonte kansasense* Bottjer, Roberts, and Hattin? *Lopha lugubris* (Conrad) *Lopha* aff. *L. bellaplicata* (Shumard) *Baculites* cf. *B. schencki* Matsumoto *Prionocyclus* cf. *P. hyatti* (Stanton) *Coilopoceras* sp.			
23	Shale, calcareous, gray, interbedded with light-brown and white nodular limestone beds as follows: a) 2-inch (5-cm)-thick, light-brown limestone that is 4 ft 4 inches (1.3 m) above base; and b) 2-inch (5-cm)-thick, white limestone that is 5 ft 6 inches (1.7 m) above base of unit.	6	--	*1.83*
22	Limestone, laminated; gray, weathers light brown; resistant ledge-former.	--	9	*0.23*
21	Shale, calcareous, gray, interbedded with white, nodular limestone beds as follows: a) 2–4-inches (5–10-cm)-thick bed, 3 inches (7.6 cm) above base of unit; and b) 2-inch (5-cm)-thick bed, 1 ft 7 inches (48 cm) above base.	3	6	*1.07*
	USGS Mesozoic locality D11195 (from units 21, 22, and 23): *Hemiaster jacksoni* Maury *Lopha lugubris* (Conrad) *Lopha* aff. *L. bellaplicata* (Shumard) *Prionocyclus hyatti* (Stanton) *Coilopoceras* sp. rudistid fragment			
20	Limestone pebble and cobble bed primarily composed of internal molds of ammonites and bivalves; pebbles and cobbles weather dark brown, are worn, burrowed, and encrusted, and have been phosphatized and mineralized by iron; unit may lie directly on underlying limestone or be separated from it by 2–3 inches (5–7.5 cm) of shale.	--	6	*0.15*
	USGS Mesozoic locality D11194: *Serpula* sp. *Hemiaster jacksoni* Maury membraniporoid bryozoan *Inoceramus howelli* White? *Pycnodonte kansasense* Bottjer, Roberts, and Hattin? *Pycnodonte* sp. *Veniella* sp. internal molds of gastropods *Morrowites depressus* (Powell) *Romaniceras* sp. *Collignoniceras woollgari woollgari* (Mantell) *Prionocyclus hyatti* (Stanton) *Neoptychites* cf. *N. cephalotus* (Courtiller) *Coilopoceras* sp. ray tooth			
19	Limestone, white, nodular, resistant.	--	6	*0.15*
	USGS Mesozoic locality D11193: *Hemiaster jacksoni* Maury *Pycnodonte* sp. *Collignoniceras woollgari* (Mantell) *Spathites rioensis* Powell *Neoptychites* sp.			
18	Shale, calcareous, gray; weathers yellow, with occasional hard limy beds; soft, slope-forming unit; 6-inch (15-cm)-thick limestone lens, 10 ft (3 m) above base, contains numerous echinoids.	22	--	*6.71*
	USGS Mesozoic locality D11192: *Hemiaster jacksoni* Maury			
17	Limestone, massive; weathers light brown; burrowed, has flat upper surface and down-curving lower surface; weathers to blocks up to 3 ft (1 m) across; major bench-forming unit.	1	2	*0.36*
	USGS Mesozoic locality D11332: *Mytiloides subhercynicus* (Seitz) *Mammites nodosoides* (Schlüter) *Kamerunoceras turoniense* (d'Orbigny) *Hoplitoides* sp.			
16	Shale, calcareous, gray; weathers yellowish gray with minor lenses of interbedded limestone as follows: a) 4-inch (10-cm)-thick bed, 2 ft (61 cm) above base; and b) 1-ft (31-cm)-thick bed, 5 ft (1.5 m) above base of unit.	9	--	*2.74*
	USGS Mesozoic locality D11331 (from 4 ft 6 inches [1.37 m] above base of unit): *Mammites nodosoides* (Schlüter) *Morrowites depressus* (Powell)			
15	Limestone; weathers yellowish brown; massive resistant ledge former.	--	7	*0.18*
	USGS Mesozoic locality D11191:			

TABLE 11 (con't)

Unit	Lithology	Thickness ft	inches	*m*
	Mytiloides mytiloides (Mantell) *Mammites nodosoides* (Schlüter) *Morrowites depressus* (Powell) *Fagesia*? sp.			
14	Shale, calcareous; weathers yellow.	2	3	*0.69*
13	Limestone, buff, thin-bedded, granular; resistant ledge former.	--	4	*0.10*
12	Shale, calcareous; weathers yellow.	2	--	*0.61*
11	Limestone, buff, thin-bedded; resistant ledge former.	--	5	*0.13*
10	Shale, calcareous; weathers yellow.	6	--	*1.83*
9	Limestone, buff, thin-bedded, resistant ledge former.	--	3.5	*0.09*
	USGS Mesozoic locality D11329: *Mammites nodosoides* (Schlüter)			
8	Shale, calcareous; weathers yellow.	2	--	*0.61*
7	Limestone, nodular; weathers light brown; resistant ledge former.	--	4	*0.10*
6	Shale, calcareous; weathers yellow, contains interbedded limestones and calcarenites as follows: a) 5-inch (13-cm)-thick, white-weathering limestone that is 5 ft (1.5 m) above base; b) 6-inch (15-cm)-thick limestone that is 9 ft 3 inches (2.8 m) above base; and c) 3.5-inch (9-cm)-thick limestone that is 11 ft 3 inches (3.4 m) above base.	14	3	*4.34*
	USGS Mesozoic locality D11328 (from unit 6c): *Mytiloides mytiloides* (Mantell) *Mammites*? sp. USGS Mesozoic locality D11327 (from unit 6b): *Mytiloides mytiloides* (Mantell) *Lewesiceras*? cf. *Lewesiceras sharpei* (Spath) *Mammites*? sp. *Kamerunoceras*? sp. USGS Mesozoic locality D11326 (from 2-inch (5-cm)-thick calcarenite beds 3 ft 2 inches (96.5 cm) and 1 ft 2 inches (35.6 cm) above unit 6a): *Mytiloides* aff. *M. duplicostatus* (Anderson) *Mammites*? sp. USGS Mesozoic locality D11325 (from unit 6a): *Mytiloides* aff. *M. duplicostatus* (Anderson)			
5	Limestone, fine-grained, laminated; weathers light brown mottled with white and dark brown.	--	2.5	*0.06*
4	Shale, calcareous; weathers yellow.	4	--	*1.22*
3	Limestone, calcarenitic, buff, flat upper surface with down-curving lower surface; weathers to large blocks; prominent ledge former.	--	8	*0.20*
	USGS Mesozoic locality D11190: *Mytiloides* aff. *M. duplicostatus* (Anderson) *Anisomyon* aff. *A. frontierensis* Sidwell *Choffaticeras*? sp. *Mammites nodosoides* (Schlüter) *Fagesia* sp.			
2	Shale, calcareous; weathers yellow with interbedded tan-weathering limestones as follows: a) 10-inch (25-cm)-thick calcarenitic, nodular limestone at base; b) 8-inch (20-cm)-thick, nodular limestone that is 2 ft (61 cm) above base; c) 3-inch (8-cm)-thick, nodular limestone that is 4 ft (1 m) above base; d) 4-inch (10-cm)-thick limestone with conspicuously burrowed top that is 7 ft (2 m) above base; e) 4-inch (10-cm)-thick limestone that is 10 ft (3 m) above base; f) 4-inch (10-cm)-thick limestone that is 12 ft (4 m) above base; g) 2-inch (5-cm)-thick limestone that is 14 ft 6 inches (4 m) above base, and h) 1.5-inch (4-cm)-thick limestone that is 17 ft (5 m) above base.	23	--	*7.01*
	USGS Mesozoic locality D11330 (from unit 2h): *Mytiloides* aff. *M. duplicostatus* (Anderson) USGS Mesozoic locality D11189 (from unit 2d): *Mytiloides* aff. *M. duplicostatus* (Anderson) *Vascoceras*? sp. USGS Mesozoic locality D11323 (from unit 2c): *Mytiloides* aff. *M. duplicostatus* (Anderson) USGS Mesozoic locality D11322 (from unit 2a): *Mytiloides* aff. *M. duplicostatus* (Anderson) *Vascoceras* sp.			
	Total measured thickness of shale and limestone member.	100	1	*30.51*
	Boquillas Limestone *Flaggy limestone member*			
1	Limestone, thin-bedded, laminated, silty, yellowish-brown; weathers to salmon; contains thin, gray, crystalline, nodular limestones 6–12 ft (2–4 m) above base; basal			

TABLE 11 (con't)

Unit	Lithology	Thickness ft	inches	m
	contact of unit is slightly undulating and contains pockets of silicified brown to reddish-brown fossils.	55	--	*16.76*
	USGS Mesozoic locality D11324 (from 45 ft [14 m] above base of unit):			
	Nigericeras scotti Cobban?			
	USGS Mesozoic locality D11321 (from 20 ft [6 m] above base of unit):			
	Inoceramus prefragilis Stephenson			
	Calycoceras cf. *C. canitaurinum* (Haas)			
	USGS Mesozoic locality D11320 (from 6 to 12 ft [2 to 4 m] above base of unit):			
	Inoceramus arvanus Stephenson			
	I. rutherfordi Warren			
	Ostrea beloiti Logan			
	Hamites (Stomohamites) simplex d'Orbigny			
	Acanthoceras sp.			
	Pseudocalycoceras cf. *P. harpax* (Stoliczka)			
	USGS Mesozoic locality D11319 (from the base of the Boquillas):			
	Inoceramus arvanus Stephenson?			
	Ostrea beloiti Logan			
	Aphrodina? sp.			
	Anchura sp.			
	Ostlingoceras brandi Young			
	O. davisense Young			
	Hypoturrilites youngi Clark			
	Desmoceras (Pseudouhligella) elgini Young			
	Forbesiceras brundrettei Young			
	Total measured thickness of flaggy limestone member.	55	--	*16.76*
	Total measured thickness of Boquillas Limestone.	155	1	*47.27*
	Buda Limestone (not measured).			

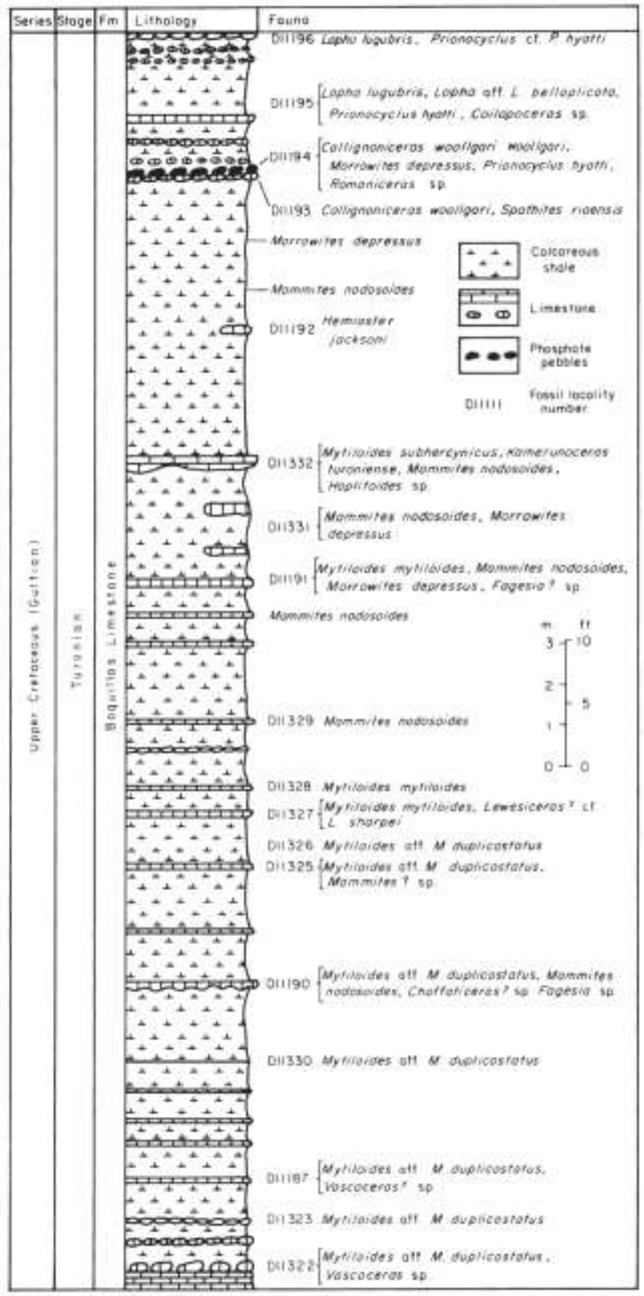

FIGURE 24—GRAPHIC SECTION OF UPPER 104 FT (31 M) OF BOQUILLAS LIMESTONE EXPOSED AT GOLD HILL SHOWING LITHOLOGIC AND FAUNAL DETAIL IN UPPER SHALE AND LIMESTONE MEMBER.

These collections indicate an early Cenomanian to early Turonian age for the flaggy limestone member and an early to late Turonian age for the shale and limestone member (fig. 24). A significant middle Turonian disconformity lies in the upper part of the shale and limestone member. This disconformity is marked by a 3-6-inch-thick bed of phosphatized pebbles and cobbles that contains faunal elements of two middle Turonian ammonite zones. The contact of the Boquillas with the underlying Buda Limestone also is disconformable.

Previous work

The Gold Hill outcrop may have been noted long ago by Adkins (1932, p. 431), who reported that

> From the northern and eastern slopes of Gomez Peak, northern Jeff Davis County, Mr. A. H. Dunlap reports an Eagle Ford section consisting of (a) about 250 to 300 feet of beds, the base in undulating contact with the Buda limestone; their lower half consists of hard, ringing, thin-bedded salmon colored Boquillas flagstone, their upper half of alternating flagstones and yellow shales which contain near the top *Scaphites*, *Prionotropis*, a three-foot ammonite, *Inoceramus* cf. *labiatus* and other fossils. . . .

Brand and DeFord (1962), who mapped the Kent quadrangle, noted that the best exposure of the Boquillas on the quadrangle was at Gold Hill. They observed that the Boquillas Limestone was fossiliferous at Gold Hill, but that most of the fossils were poorly preserved. They repeated a list of ammonites described by Young (1958) from the base of the Boquillas at a locality approximately 9 mi (15 km) southeast of Gold Hill but listed none from Gold Hill itself.

Powell (1967, p. 313-319, figs. 2-5) reported on three large specimens of *Morrowites depressus* (Powell) that came from the Boquillas at Gold Hill, and he presented a section of the Boquillas measured at a locality approximately 1.5 mi (2.5 km) south of Gold Hill. A few fossils were listed from the measured section, but most were identified only to the genus. Only *M. depressus* was mentioned from Gold Hill.

ACKNOWLEDGMENTS—We thank Leonard Lethco of the Lethco Ranch for permission to measure the stratigraphic section and collect fossils at Gold Hill. Robert E. Burkholder of the U.S. Geological Survey, Denver, Colorado, helped collect fossils and printed the outcrop photographs. M. E. MacLachlan and C. M. Molenaar, both of the U.S. Geological Survey, Denver, critically reviewed this paper. The work that led to this paper was done in cooperation with the Texas Bureau of Economic Geology, Austin, Texas.

Faunal sequence

The oldest molluscan fauna at Gold Hill occurs sporadically at the base of the Boquillas Limestone, where pockets of silicified fossils seemed to have accumulated in depressions cut into the top of the Buda Limestone. The fossils are mostly small desmoceratid ammonites but include fragments of larger ammonites, bivalves, and gastropods. Young (1958) described the ammonites and illustrated one of the gastropods from the base of the Boquillas at a locality southeast of Gold Hill, where the fossils also are silicified. Among the ammonites at Young's locality is a species that Young described as *Neopulchellia brundrettei.* Young and Powell (1976, p. 25.15-25.24) later assigned this species to *Forbesiceras* and designated a zone of *F. brundrettei.* A fragment of a large turrilitid ammonite described as *Hypoturrilites n.* sp. by Young (1958, p. 287, pl. 39, fig. 32, text fig. 1g) was later named *H. youngi* Clark (Clark, 1965, p. 52, pl. 19, fig. 6). Several very large specimens collected from Gold Hill reveal that this species attained whorl diameters of at least 110 mm. The rest of the species of ammonites described by Young, as well as the gastropod illustrated by him as *Anchura* sp., also occur at Gold Hill.

Hard, gray, limestone beds, 6-12 ft (2-4 m) above the base of Boquillas at Gold Hill, contain *Inoceramus rutherfordi* Warren in addition to *I. arvanus* and *Ostrea beloiti.* In New Mexico, Colorado, Kansas, Wyoming, and South Dakota, *I. rutherfordi* is restricted to the upper part of the middle Cenomanian zone of *Acanthoceras amphibolum* Morrow; whereas, *I. arvanus* is generally associated with the underlying subzone of *A. alvaradoense* Moreman. *Ostrea beloiti* had great geographic distribution during that time (Cobban and Hook, 1980, fig. 3).

Inoceramus prefragilis Stephenson is fairly abundant in the Boquillas approximately 17-33 ft (5-10 m) above the base at Gold Hill. A fragment of the ammonite *Calycoceras* cf. *C. canitaurinum* (Haas), found as float from this part of the formation, indicates the early late Cenomanian zone of *Calycoceras canitaurinum* (Haas).

Very poor impressions of ammonites in the upper part of the lower member of the Boquillas suggest some nearly smooth vascoceratid ammonite such as *Nigericeras scotti* Cobban (1971, p. 18, pl. 9, figs. 1-4; pl. 18, figs. 1-9; text figs. 15-17). In southeast Colorado, this ammonite occurs in the Greenhorn Formation just above beds that contain the *Sciponoceras gracile* fauna of late Cenomanian age. *Nigericeras scotti* has been assigned an early Turonian age by Cobban (1971, p. 18), Cobban and Hook (1980, fig. 1), and Hook and Cobban (1979, fig. 1; 1981, fig. 1).

Ammonites collected from most of the lower half of the shale and limestone member of the Boquillas at Gold Hill are poorly preserved. Fragments of a vascoceratid ammonite associated with *Mytiloides aff. M. duplicostatus* (Anderson) occur in the basal quarter of this member. This association suggests an early Turonian stratigraphic level near that of bed 97 in the measured section of the Bridge Creek Limestone Member of the Greenhorn Formation near Pueblo, Colorado, where *Vascoceras (Greenhornoceras) birchbyi* Cobban and Scott occurs with *M. aff. M. duplicostatus* (Cobban and Scott, 1972, p. 23; *M. aff. M. duplicostatus* recorded as *Inoceramus labiatus).*

Mammites nodosoides (Schlüter), of latest early Turonian age, first appears at the top (unit 3) of the basal quarter of the shale and limestone member and persists upward through most of the member. The upper part of its range overlaps that of *Morrowites depressus* (Powell).

The occurrence of *M. depressus* in the upper part of the zone of *Mammites nodosoides* was noted at other localities in the Western Interior (Cobban and Hook, 1979, p. 6, 10). A thick bed of limestone (unit 17), which forms a conspicuous ledge around the upper part of Gold Hill (fig. 25), contains *Mytiloides subhercynicus* (Seitz) and *Kamerunoceras turoniense* (d'Orbigny) in addition to *M. nodosoides.*

A nodular bed of limestone (unit 19), about 11 ft (3 m) below the top of Gold Hill, contains the important ammonites *Collignoniceras woollgari* (Mantell) and *Spathites rioensis* Powell of earliest middle Turonian age.

Unit 20 consists of phosphatic nodules and fossils that mark a disconformity and hardground development on top of unit 19 (fig. 26). Fossils from unit 20 consist of worn, encrusted, phosphatized fragments of internal molds of *Prionocyclus hyatti* (Stanton), *Collignoniceras woollgari woollgari*, *Morrowites depressus* (Powell), and *Neoptychites* cf. *N. cephalotus* (Courtiller) that have been derived from older rocks. Most of the subzone of *Collignoniceras woollgari woollgari* and all of the overlying subzone of *C.*

FIGURE 25—CLOSEUP PHOTOGRAPH OF GOLD HILL LOOKING NORTH, SHOWING UPPER PART OF SHALE AND LIMESTONE MEMBER OF BOQUILLAS LIMESTONE. Prominent bench-forming limestone, which is 33 ft (10 m) below top of Gold Hill, is unit 17 of measured section.

FIGURE 26—PHOSPHATIZED COBBLE OF UNIT 20 LYING DISCONFORMABLY ON NODULAR LIMESTONE OF UNIT 19, WHICH IS 11.1 FT (3.4 M) BELOW TOP OF GOLD HILL. Unit 20 is composed of worn, encrusted, phosphatized, internal molds of fossils that represent two superimposed ammonite zones.

woollgari regulare (Haas) as well as the zone of *Subprionocyclus? percarinatus* (Hall and Meek) are missing at Gold Hill. This disconformity may be related to the condensed zone of Adkins (1932, p. 435, 436) at the top of the Eagle Ford Shale at Austin, Texas, where *Prionocyclus hyatti* has been recorded in association with older fossils and phosphatic pebbles (Young and Powell, 1976). A widespread discontinuity surface in New Mexico at the base of the *Collignoniceras woollgari woollgari* Subzone was also noted by Hook and Cobban (1981).

The highest bed (unit 24) in the Boquillas Limestone on the top of Gold Hill contains a few valves of *Lopha lugubris* (Conrad), an oyster known elsewhere in the Western Interior mostly from the Juana Lopez Member (upper Turonian) of the Mancos and Carlile Shales (Hook and Cobban, 1980, p. 44, 45). A limestone unit higher in the Boquillas is exposed on the hill just south of Gold Hill and near the road about 0.2 mi (0.4 km) southeast of Gold Hill. Both outcrops contain *Mytiloides fiegei* Troger of very late Turonian age.

Faunal comparison with New Mexico

The Cenomanian—Turonian faunal sequence in New Mexico is better known than that of west Texas and, thus, can serve as a standard of comparison for the faunas from Gold Hill (fig. 27). Although most of the New Mexico zones can be recognized at Gold Hill on the basis of either the zonal index or associated fauna, some differences exist. For example, the *Forbesiceras brundrettei* fauna that occurs at the base of the Boquillas Limestone has never been found in New Mexico.

The barren interval at Gold Hill above *the Calycoceras canitaurinum* Zone is less than 10 ft (3 m) thick; yet, the interval must represent at least five ammonite zones. The absence of the *Sciponoceras gracile* (Shumard) fauna, which is widespread in Texas (Young and Powell, 1976) and throughout the Western Interior (Cobban and Scott, 1972), combined with the thin stratigraphic interval indicates the possibility of an unconformity. Also, Hook and Cobban (1981) have described several discontinuity surfaces from southwest New Mexico that are of the same age as this barren interval. However, neither an unconformity nor a discontinuity surface could be recognized in this interval on the basis of physical evidence.

The *Collignoniceras woollgari regulare* Subzone and the *Subprionocyclus? percarinatus* Zone are missing at Gold Hill because of a mid-Turonian disconformity that juxtaposes the *Prionocyclus hyatti* fauna with the *Collignoniceras woollgari woollgari fauna in* a 6-inch-thick phosphate pebble bed.

All of the remaining late Turonian faunal zones that can be recognized in New Mexico are probably present in the Boquillas near Gold Hill, although faunal evidence at present is meager and confined primarily to reconnaissance collections. *Lopha lugubris*, which was found in the limestone that caps Gold Hill, has a vertical range that spans both the upper part of the *Prionocyclus macombi* Zone and the overlying *P. wyomingensis* Zone. Likewise, *Mytiloides fiegei* has been collected in New Mexico from both the *Prionocyclus novimexicanus* Zone and the overlying *P. quadrates* Zone. However, the occurrence of *Lopha aff. . L. bellaplicata* in the same bed with *L. lugubris* (USGS Mesozoic locality D11196) may indicate the presence of a condensed sequence or a discontinuity surface in unit 24, the 4-inch-thick limestone that caps Gold Hill.

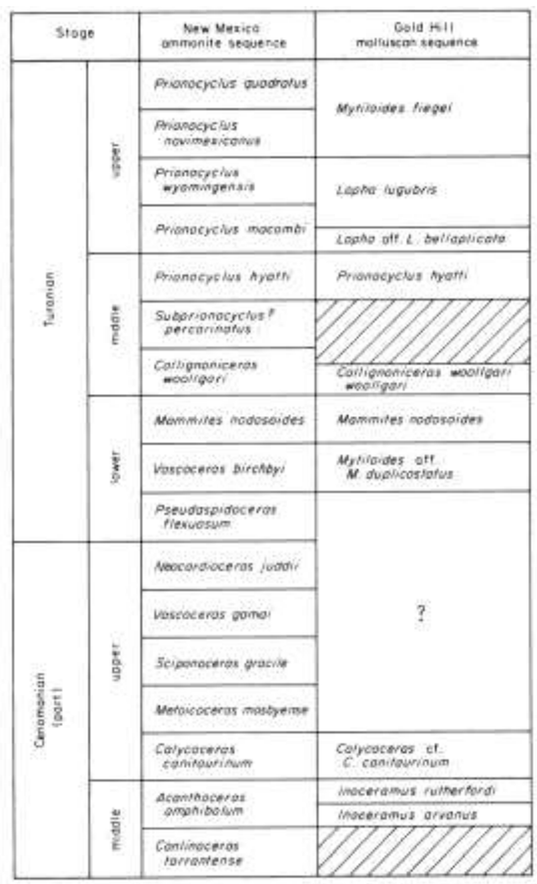

FIGURE 27—CHART SHOWING FAUNAS FROM BOQUILLAS LIMESTONE AT GOLD HILL COMPARED TO AMMONITE ZONATION FOR THE MIDDLE CENOMANIAN THROUGH TURONIAN STAGES IN NEW MEXICO. Column on left shows sequence of ammonite zones as they occur in New Mexico; column on right shows fauna from Gold Hill that is indicative of the corresponding ammonite zone in New Mexico.

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Contents of pocket

SHEET 1—Stratigraphic cross sections from (A) Moreno Hill to Gallup and **(B)** Upper Nutria to Carthage.

Editor:	Marla D. Adkins-Heljeson
Drafters:	Teresa Mueller, Debra Vetterman
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Explanation

General lithology symbols

upper coarse, lower coarse, upper medium, lower medium, upper fine, lower fine, upper very fine, lower very fine

- Sandstone. On sections where column excursion is to left, column width indicates visual estimate of median grain size. Single row of dots extending outside of column represents thin layer (< 1 ft) of coarser grains, the size of which is indicated. In essence, the left side of the column is a grain-size profile
- Sandstone. On sections where column excursion is to right, no specific grain size is implied
- Siltstone
- Shale or claystone
- Silty shale or mudstone
- Coal
- Interbedded sandstone and shale or siltstone in which sandstone beds are thin or too subdued to separate from sequence. Proportions of each are indicated
- Interbedded sandstone and shale or siltstone in which sandstone proportion is less than 20%
- Partially covered interval
- Covered interval; lithology inferred if filled in
- Limestone
- Thin limestone beds (in shale)

Accessories, modifiers, and sedimentary structures

- Pebbles
- Shale clasts or galls
- Concretions
- Carbonaceous
- Calcareous
- Bentonite or bentonitic
- Crossbedded
- Trace fossils (burrows)
- Bioturbated; that is, churned
- Root casts
- Glauconite

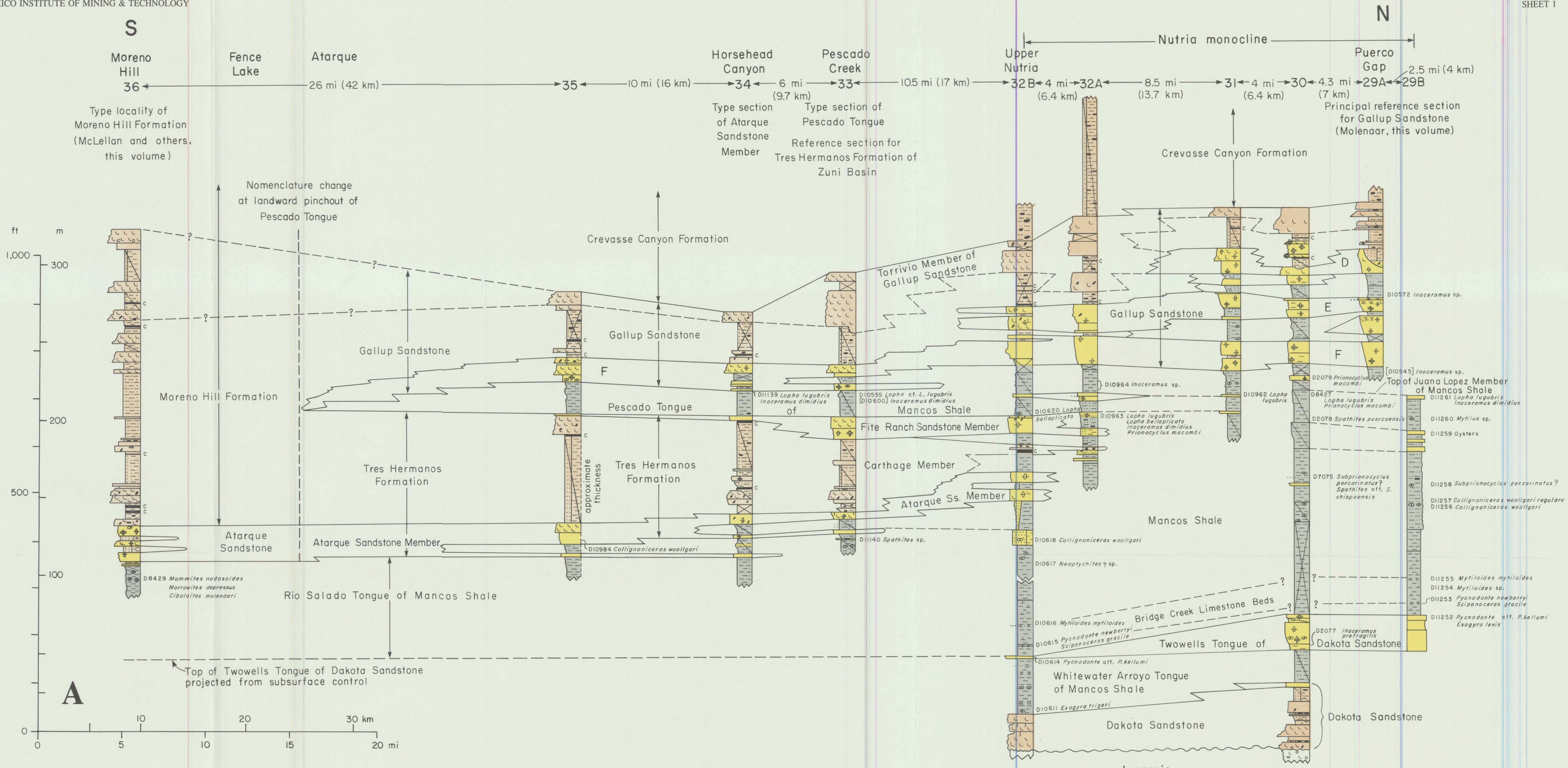
Miscellaneous

D1044—USGS number of fossil collection. If notation is in brackets, collection has been projected into section from nearby locality

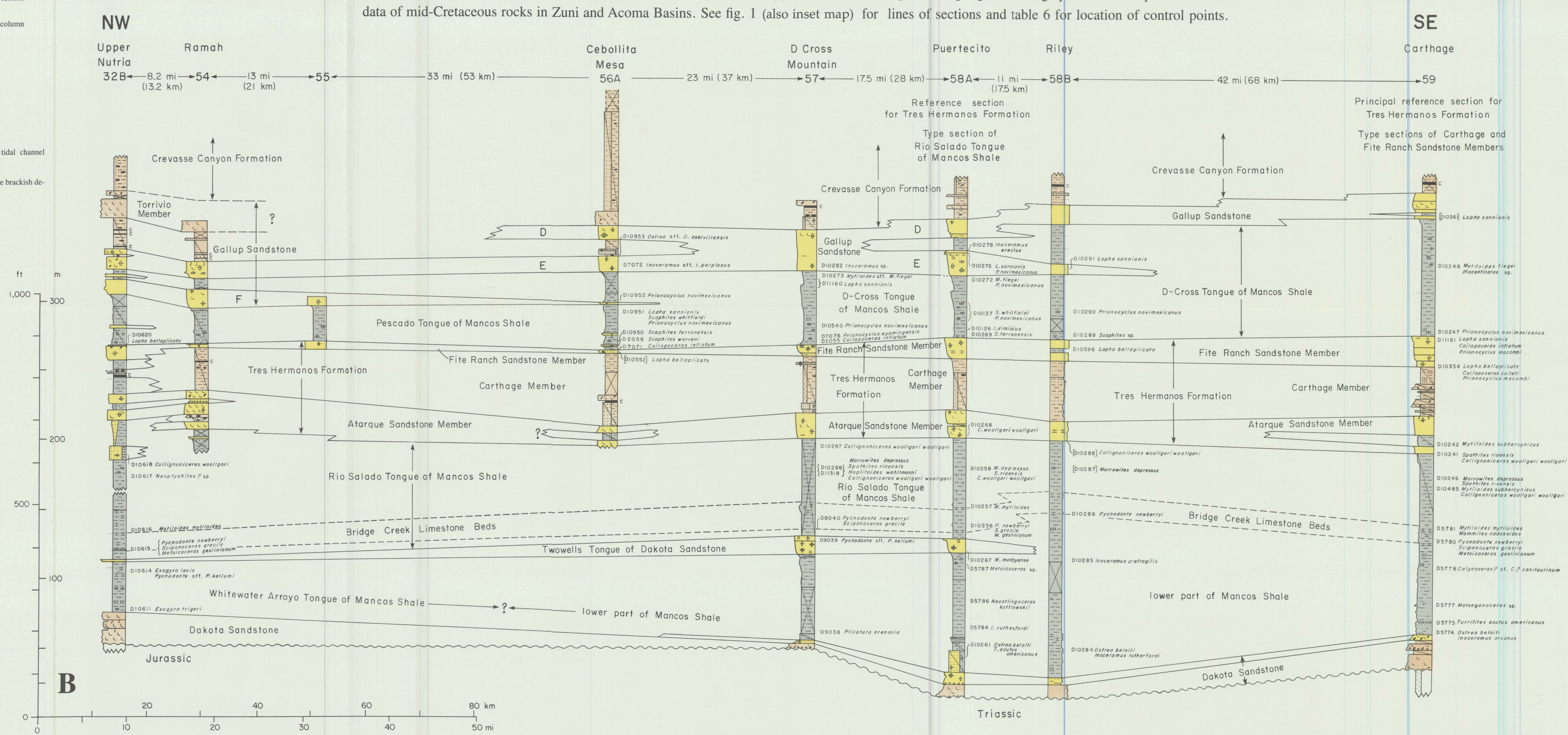
Note: Thickness is approximate where right side of column is dashed.

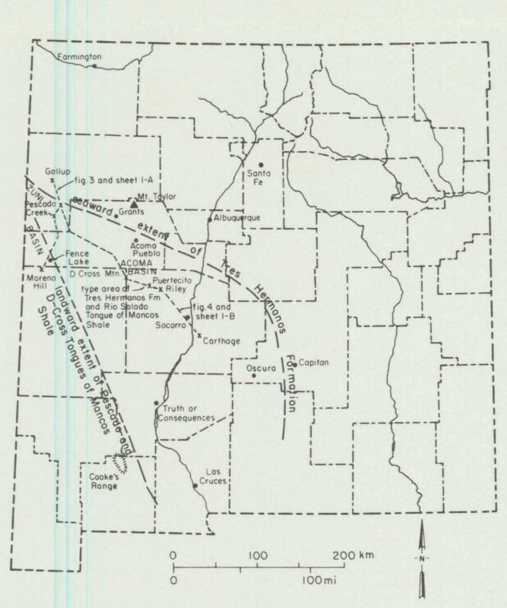
Color legend for primary facies

- Marine shale and siltstone
- Marine sandstone including shoreline and tidal channel sandstone
- Nonmarine deposits including marginal marine brackish deposits



Stratigraphic cross sections from **(A)** Moreno Hill to Gallup and **(B)** Upper Nutria to Carthage showing regional stratigraphic relationships and faunal data of mid-Cretaceous rocks in Zuni and Acoma Basins. See fig. 1 (also inset map) for lines of sections and table 6 for location of control points.





Location map showing lines of section for sheet 1 and for figs. 3 and 4, seaward extent of Tres Hermanos Formation, and landward extent of Pescado and D-Cross Tongues of Mancos Shale.

Drafted by T. A. Mueller

Stratigraphy and revision of nomenclature of Upper Cenomanian to Turonian (Upper Cretaceous) rocks of west-central New Mexico

by S. C. Hook, C. M. Molenaar, and W. A. Cobban

1983